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(54) Title: MIMICKING PEPTIDES IN CANCER THERAPY

(57) Abstract

Peptide mimicks of MUC1 or other cancer peptides which can be included in cancer vaccines and used in therapeutic methods for the treatment of cancer patients.

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MIMICKING PEPTIDES IN CANCER THERAPY

FIELD OF THE INVENTION

The present invention relates to anti-Galα(1,3)Gal antibody binding peptides and to the use of such peptides in cancer therapy.

BACKGROUND OF THE INVENTION

A successful vaccine for cancer immunotherapy requires the identification of a suitable target antigen and the production of a cytotoxic T cell response (25). Cancer mucins, particularly MUC1 (2), provide a suitable target in cancer as there is a 10-fold increase in mucin expression, a ubiquitous (rather than polar) distribution on the cell surface, and altered glycosylation which reveals normally hidden peptide sequences (particularly an anti-MUC1 antibody detected epitope: the amino acids APDTR from the variable number of tandem repeat region (VNTR) (27). These changes apparently absent in normal mucin generate new targets for immunotherapy (28). The APDTR sequence is immunogenic in mice leading to antibody formation whether the antigen is administered as purified mucin (MHFG) or peptides (29) Such studies of immunogenicity in mice would be of little relevance to humans, were it not for the findings that tumour specific CTLp exist in the lymph nodes of patients with cancers of either breast, ovary or pancreas (30). Thus, theoretically, patients could be immunised with MUC1 peptide sequences to convert their CTLp into functional CTLs which should have a therapeutic anti-cancer effect.

The applicants have previously shown in a murine MUC1$^+$ tumour model, that a 20mer MUC1 VNTR peptide sequence (made as a GST fusion protein (FP)) when coupled to oxidised mannan (M-FP-oxidised) generates H-2 restricted CTLs which protects from challenge with MUC1$^+$ mouse tumours, and in addition leads to the rapid reversal of the growth of established MUC1$^+$ tumours (stimulation of T_1 T cells) (International Patent Application No. PCT/AU9400789) (31,32). Based on the foregoing, adenocarcinoma patients have been immunised with M-FP and antibody and cellular responses generated Nonetheless it is of interest that patients could be immunised, albeit weakly, against a self peptide, and both T and B cell tolerance appears to be

broken. Despite the immune responses noted, MUC1 is a self peptide occurring in normal mucin in tissues such as breast, kidney, lung, ovary. As it is ubiquitous, anti-mucin responses have the potential for inducing autoimmune diseases against any of the normal tissues

Surprisingly, when conducting investigations with peptides developed to bind with anti-Galα(1,3)Gal antibodies in relation to the problem of hyperacute xenograft rejection, it was found by the present inventors that the human mucin peptides (arising from muc1-muc4 genes, listed as muc pep 1-11 in table 1) also bound to the anti-Galα(1,3)Gal antibody (see copending international patent application filed on 27 September 1996, also based on Australian Patent Application No. PN 5680/95). Given that the peptides developed to bind to anti-Galα(1,3)Gal antibodies exhibit similar antibody binding characteristics to the human mucin peptides, it was postulated that such peptides could be useful in generating an immune response against tumour antigens. Being non-self peptides this immune response has the potential to be greater than that generated by self peptides such as MUC1.

Accordingly therefore, it is an object of the present invention to develop novel cancer immunotherapy vaccines and methods of cancer therapy. Other objects of the present invention will become apparent from the following description thereof.

SUMMARY OF THE INVENTION

According to one embodiment of the present invention there is provided a cancer vaccine comprising a peptide which mimicks MUC1 or other cancer peptides and one or more pharmaceutically acceptable carrier or diluent, optionally in association with an appropriate carrier peptide or another therapeutic agent.

According to another embodiment of the present invention there is provided a method of treatment of a human patient suffering from or prone to suffer from cancer, which comprises administering to said patient an effective amount of a cancer vaccine comprising a peptide which mimicks MUC1 or other cancer peptides, and optionally one or more pharmaceutically acceptable carrier or diluent, optionally also in association with one or more appropriate carrier peptides or another therapeutic agents.

DETAILED DESCRIPTION OF THE INVENTION

It is to be recognised that throughout this specification, unless the context requires otherwise, the word "comprise", or variations thereof such as "comprises" or "comprising", will be understood to imply the inclusion of a stated element or integer or a group of elements or integers but not the exclusion of any other element or integer or group of elements or integers.

It was recognised by the inventors of the present application that α-galactosyl sugars such as d-galactose, melibiose, stachyose, methyl-α-d-galactopyranoside, D-galactosamine and derivatives thereof bind to anti-Galα(1,3)Gal antibodies. It was also noted by the present inventors that the Galα(1,3)Gal epitope is present on the surface of endothelial cells of animals other than higher primates (humans and old world monkeys). Higher primates do not make Galα(1,3)Gal as they lack a functional α(1,3) galactosyl transferase due to the presence of multiple in-phase stop codons and multiple insertions and deletions leading to frame shifts within the α(1,3)galactosyl transferase genes, which result in non-functional pseudo-genes (8,7). All humans however, have natural antibodies to Galα(1,3)Gal (15,18), which is probably due to immunisation with bacteria which carry α-linked Gal as part of the lipopolysaccharide.

It is also known that the IB4 lectin which is a plant glycoprotein from the species *Griffonia simplicifolia*, is capable of binding to the Galα(1,3)Gal epitope. On this basis therefore, the present inventors proposed to locate peptides capable of binding to the anti-Galα(1,3)Gal antibody by screening peptides for binding with the IB4 lectin. A multitude of random amino acid sequence octapeptides was synthesised and displayed in a phage display library and screened for binding activity against the IB4 lectin, the surprising result of which was that a number of synthesised peptides demonstrated binding with the IB4 lectin. Similarly, other known peptides were also screened for binding against the IB4 lectin and it was surprisingly also found that the IB4 lectin bound to the protein core of the human mucin peptides (MUC 1-7) which are highly expressed on the surface of tumour cells (2,19) and which in this situation have an altered pattern of glycosylation which leads to exposure of the protein core (3). It has since been demonstrated by the present inventors that the IB4 binding synthetic peptides (Gal pep 1 to Gal pep 7) obtained from the random peptide library and the mucin peptides both bind to the anti-Galα(1,3)Gal antibody, and can be utilised in cancer therapy protocols.

The phrase within the specification peptides "mimicks MUC1 or other cancer peptides" encompasses all peptides which demonstrate analogous binding in the groove of class I MHC molecules. An indicator of mimicking MUC1 is binding to IB4 or anti-Galα(1,3)Gal antibodies. Relative affinities of peptides for the anti-Galα(1,3)Gal antibody or for IB4 can be calculated by comparing the molar concentration required to obtain 50% inhibition of the binding of antibody by lectin or sugars, using an ELISA (enzyme-linked immunosorbent assay). The details of this technique will be described more fully in the examples under the heading "materials and methods". The peptides of the invention include peptides having only as few as 3 amino acids up to polypeptides including up to or exceeding 200 amino acids. Although, as will be discussed in further detail, preferred peptides of the invention include the consensus sequence ArXXArZ (as defined below) and the peptides Gal pep 1 to Gal pep 7, this is in no way to be considered limiting upon the invention. Other peptides which demonstrate the requisite cancer peptide mimicking, and particularly peptides which are similar to Gal pep 1 - Gal pep 7 but which include one or more deletions or modifications to the amino acid sequence are to be considered to fall within the scope of the invention.

Although not to be considered limiting upon the scope of the invention, it is noted that the peptides exhibiting antibody binding characteristics which were located from the random amino acid library screening have the following consensus sequence:

ArXXArZ

where Ar = tryptophan (W), phenylalanine (F) or tyrosine (Y)

X = a small aliphatic or polar amino acid residue such as for example glutamic acid (E), serine (S) aspartic acid (D), glycine (G),isoleucine (I), alanine (A) or asparagine (N).

Z = branched aliphatic amino acid such as for example valine (V) isoleucine (I), or leucine (L)

Particularly preferred are the peptides shown in Fig. 1 as Gal pep 1 to Gal pep 7 which each conform with the above consensus sequence.

Other preferred compounds are the mucin glycopeptides MUC 1 to MUC 7 (4).

The most preferred peptide however, is Gal pep 1 which has the sequence DAHWESWL, and which can mimic the conformation of the MUC1 VNTR peptides SAPDTRPAP/APDTRPAPG (which bind H-2D^d and H-2L^d respectively).

The applicants have previously shown that mice immunised with mannan-MUC1-peptides make cytotoxic T cells (CTLs), little antibody and are protected from MUC1$^+$ tumour growth. The same specific anti-MUC1 responses can be produced by immunising with the peptides of the invention and particularly the DAHWESWL peptide linked to KLH, in that anti-MUC1 (and anti-DAHWESWL) CTL responses can be induced or antibody produced and more particularly, specific tumour protection occurs of magnitude greater than or similar to that obtained with mannan-MUC1 peptide immunisation.

It is also possible that the peptides as outlined above which accord with the present invention can be conjugated to other species. The other species comprehended include all chemical species which can be fused to the peptide in question without affecting the binding of the peptide by T-cells. Specific examples are for example other antigens which may elicit a separate immune response, carrier molecules which may aid absorption or protect the peptide concerned from enzyme action in order to improve the effective half life of the peptide. Other possibilities are conjugation of peptides to solid or liquid phases for use in immuno assays for diagnostic or therapeutic purposes. Specific examples of peptide conjugation are conjugation to other serum proteins or macromolecules.

The present invention relates to methods of cancer therapy which involve the peptides according to the present invention. In particular vaccines which include peptides according to the invention can be administered to cancer patients to induce immunity to the mucin core of aberrantly glycosylated mucins which are highly expressed on the surface of tumour cells. Mucins are expressed in adenocarcinomas in cancer of the breast, liver, colon, prostate and others. In treating cancer it may useful to conjugate peptides to other carriers to induce T cells capable of recognising and destroying cancer cells.

The present invention also relates to methods of vaccinating human subjects as a method of

cancer therapy or treatment for auto-immune disease. In this way the inventive vaccine can be administered to human patients who are either suffering from, or prone to suffer from cancer or autoimmune disease.

In cancer therapy it is possible to immunise with peptide-carrier combination to induce T cells capable of recognising and destroying target cancer cells or alternatively immunisation to induce antibodies with anti-tumour activity.

The vaccine according to the invention may contain a single peptide according to the invention or a range of peptides which cover different or similar epitopes. In addition, or alternatively, a single polypeptide may be provided with multiple epitopes. The latter type of vaccine is referred to as a polyvalent vaccine.

In a preferred embodiment of the invention the peptide is conjugated to a carrier protein such as for example tetanus toxoid, diphtheria toxoid or oxidised KLH in order to stimulate T cell help.

The formation of vaccines is generally known in the art and reference can conveniently be made to Remington's Pharmaceutical Sciences, 17th ed., Mack Publishing Co., Easton,Pennsylvania, USA.

For example, from about 0.05 ug to about 20 mg per kilogram of body weight per day may be administered. Dosage regime may be adjusted to provide the optimum therapeutic response. For example, several divided doses may be administered daily or the dose may be proportionally reduced as indicated by the exigencies of the therapeutic situation. The active compound may be administered in a convenient manner such as by the oral, intravenous (where water soluble), intramuscular, subcutaneous, intra nasal, intradermal or suppository routes or implanting (eg using slow release molecules by the intraperitoneal route or by using cells e g. monocytes or dendrite cells sensitised *in vitro* and adoptively transferred to the recipient). Depending on the route of administration, the peptide may be required to be coated in a material to protect it from the action of enzymes, acids and other natural conditions which may inactivate said ingredients

For example, the low lipophilicity of the peptides will allow them to be destroyed in the gastrointestinal tract by enzymes capable of cleaving peptide bonds and in the stomach by acid hydrolysis. In order to administer peptides by other than parenteral administration, they will be coated by, or administered with, a material to prevent its inactivation. For example, peptides may be administered in an adjuvant, co-administered with enzyme inhibitors or in liposomes. Adjuvants contemplated herein include resorcinols, non-ionic surfactants such as polyoxyethylene oleyl ether and n-hexadecyl polyethylene ether. Enzyme inhibitors include pancreatic trypsin inhibitor, diisopropylfluorophosphate (DEP) and trasylol. Liposomes include water-in-oil-in-water CGF emulsions as well as conventional liposomes.

The active compounds may also be administered parenterally or intraperitoneally. Dispersions can also be prepared in glycerol, liquid polyethylene glycols, and mixtures thereof and in oils. Under ordinary conditions of storage and use, these preparations contain a preservative to prevent the growth of microorganisms.

The pharmaceutical forms suitable for injectable use include sterile aqueous solutions (where water soluble) or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion. In all cases the form must be sterile and must be fluid to the extent that easy syringability exists. It must be stable under the conditions of manufacture and storage and must be preserved against the contaminating action of microorganisms such as bacteria and fungi. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol and liquid polyethylene glycol, and the like), suitable mixtures thereof, and vegetable oils. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of superfactants. The prevention of the action of microorganisms can be brought about by various antibacterial and antifungal agents, for example, chlorobutanol, phenol, sorbic acid, theomersal and the like. In many cases, it will be preferable to include isotonic agents, for example, sugars or sodium chloride. Prolonged absorption of the injectable compositions can be brought about by the use in the composition of agents delaying absorption, for example, aluminium monostearate and gelatin

Sterile injectable solutions are prepared by incorporating the active compounds in the required amount in the appropriate solvent with various of the other ingredients enumerated above, as required, followed by filtered sterilization. Generally, dispersions are prepared by incorporating the various sterilized active ingredient into a sterile vehicle which contains the basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and the freeze-drying technique which yield a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

When the peptides are suitably protected as described above, the active compound may be orally administered, for example, with an inert diluent or with an assimilable edible carrier, or it may be enclosed in hard or soft shell gelatin capsule, or it may be compressed into tablets, or it may be incorporated directly with the food of the diet. For oral therapeutic administration, the active compound may be incorporated with excipients and used in the form of ingestible tablets, buccal tablets, troches, capsules, elixirs, suspensions, syrups, wafters, and the like. Such compositions and preparations should contain at least 1% by weight of active compound. The percentage of the compositions and preparations may, of course, be varied and may conveniently be between about 5 to about 80% of the weight of the unit. The amount of active compound in such therapeutically useful compositions is such that a suitable dosage will be obtained. Preferred compositions or preparations according to the present invention are prepared so that an oral dosage unit form contains between about 0.1 ug and 2000 mg of active compound.

The tablets, pills, capsules and the like may also contain the following: A binder such as gum tragacanth, acacia, corn starch or gelatin; excipients such as dicalcium phosphate; a disintegrating agent such as corn starch, potato starch, alginic acid and the like; a lubricant such as magnesium stearate; and a sweetening agent such as sucrose, lactose or saccharin may be added or a flavouring agent such as peppermint, oil of wintergreen, or cherry flavouring When the dosage unit form is a capsule, it may contain, in addition to materials of the above type, a liquid carrier Various other materials may be present as coatings or to otherwise modify the physical form of the dosage unit. For instance, tablets, pills, or capsules may be coated with shellac, sugar or both A syrup or elixir may contain the active compound, sucrose as a

sweetening agent, methyl and propylparabens as preservatives, a dye and flavouring such as cherry or orange flavour. Of course, any material used in preparing any dosage unit form should be pharmaceutically pure and substantially non-toxic in the amounts employed. In addition, the active compound may be incorporated into sustained-release preparations and formulations.

As used herein "pharmaceutically acceptable carrier and/or diluent" includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents and the like. The use of such media and agents for pharmaceutical active substances is well known in the art. Except insofar as any conventional media or agent is incompatible with the active ingredient, use thereof in the therapeutic compositions is contemplated. Supplementary active ingredients can also be incorporated into the compositions.

It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the mammalian subjects to be treated; each unit containing a predetermined quantity of active material calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the novel dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the active material and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such an active material for the treatment of disease in living subjects having a diseased condition in which bodily health is impaired as herein disclosed in detail.

The principal active ingredient is compounded for convenient and effective administration in effective amounts with a suitable pharmaceutically acceptable carrier in dosage unit form as hereinbefore disclosed. A unit dosage form can, for example, contain the principal active compound in amounts ranging from 0.5 µg to about 2000 mg. Expressed in proportions, the active compound is generally present in from about 0.5 µg/ml of carrier. In the case of compositions containing supplementary active ingredients, the dosages are determined by reference to the usual dose and manner of administration of the said ingredients

Still another aspect of the present invention is directed to antibodies to the peptides. Such antibodies may be monoclonal or polyclonal and may be selected from naturally occurring antibodies to the peptide or may be specifically raised to the peptides. In the case of the latter, the peptides may need first to be associated with a carrier molecule. The antibodies and/or peptides of the present invention are particularly useful for immunotherapy and vaccination and may also be used as a diagnostic tool for infection or for monitoring the progress of a vaccination or therapeutic regima.

In another aspect of the invention there are provided nucleotide sequences encoding the proteins according to the present invention. Preferably the nucleotide sequence encodes Gal pep 1.

Nucleotide sequences may be in the form of DNA, RNA or mixtures thereof. Nucleotide sequences or isolated nucleic acids may be inserted into replicating DNA, RNA or DNA/RNA vectors as are well known in the art, such as plasmids, viral vectors, and the like (*Sambrook et al*, Molecular Cloning A Laboratory Manual, Coldspring Harbour Laboratory Press, NY, second edition 1989). Nucleotide sequences encoding the antibodies of the present invention may include promoters, enhances and other regulatory sequences necessary for expression, transcription and translation. Vectors encoding such sequences may include restriction enzyme sites for the insertion of additional genes and/or selection markers, as well as elements necessary for propagation and maintenance of vectors within cells.

Nucleotide sequences encoding antibodies according to the present invention may be used in homologous recombination techniques as are well known in the art *Capecchi M R*, Altering the Gene by Homologous Recombination, Science 244:1288-1292, 1989; Merleno G T, Transgenic Animals in Biomedical Research, FASEB J 5:2996-3-001,1992; Cosgrove et al, Mice Lacking MAHC class II molecules, cell 66:1051-1066, 1991; Zijlstra et al, Germ-Line Transmission of a Disrupted B2-Microglobulin Gene Produced by Homologous Recombination in Embryonic Stem Cells, Nature 342:435,1989). In such techniques, nucleotide sequences encoding the peptides according to the invention are recombined with genomic sequences in stem cells, ova or newly fertilised cells comprising from 1 to about 500 cells. Nucleotide sequences utilised in homologous recombination may be in the form of isolated nucleic sequences or in the context

of vectors. Insertion of new active genes by transgenesis is also comprehended.

The present invention will now be described with reference to the following non-limiting figures and examples.

IN THE FIGURES

Figure 1. Amino acid sequences of phage isolated by panning with the IB4 lectin. Amino acid sequences were deducted from the DNA sequence encoding the amino-terminal octapeptide of pIII from phage eluted from IB4 lectin with 200 mM α-methyl galactoside.

Figure 2. Peptide inhibition of hemagglutination. Varying concentrations of Gal pep 1 (o) or CD48 pep 1 (♦) (shown in mM on horizontal axis) were examined in a hemagglutination assay using pig RBC as targets and either (A) IB4 lectin (1μg/ml) or (B) NHS (final dilution of 1/32).

Figure 3. Cytofluorographic analsysis of inhibition produced by Gal pep 1. (A); Staining of PIEC cells with IB4 lectin (1μg/ml). (B) Staining of PIEC cells with NHS (final dilution of 1/50) and anti-human Ig (C) Staining of PBL with IB4 lectin (μg/ml). Peptides were used at 5mM (A and C) or at 20mM (B). In each panel profile "a" represents binding in the presence of Gal pep 1, and profile "b" the binding in the presence of CD48 pep 1. The profile of binding without peptide, for both the IB4 lectin and NHS, was identical to profile "b" in each panel (not shown for clarity).

Figure 4. Inhibition of cytotoxicity due to natural antibody and complement by Gal pep 1 Varying concentrations of Gal pep 1 (o) or CD48 pep 1 (♦) (shown in mM on horizontal axis) were examined in a cytotoxicity assay using NHS (final dilution of 1/25) and PIEC cells as targets. Vertical axis shows % lysis; cells were ‹95% viable and complement control was ‹10%

Figure 5. Inhibition of binding of IB4 lectin and anti-Galα(1,3)Gal IgG to Galα(1,3)Gal-BSA by oligosaccharides or peptides. Varying concentrations of inhibitors (shown in mM on horizontal axis) were examined in an Elisa for inhibition of IB4 (16μg/ml) (A, B) or anti-

Galα(1,3)Gal IgG antibodies (75μg/ml) (C,D). Inhibitors used: oligosaccharides - glucose (♦), Galα(1,3)Gal (o) and melibiose (●) (A and C); peptides - Gal pep 1 (o) or CD48 pep 1 (♦) (B and D). Vertical axis shows OD at 405 nm.

Figure 6. Peptide inhibition of IB4 lectin binding to pig endothelial cells. Varying concentrations of peptides (shown in mM on horizontal axis) were explained for ability to inhibit the binding of IB4 lectin (1μg/ml) to the PIEC cells using cytofluorographic analysis. (a) Gal pep 1 (□), Muc pep 1 (o). (b) Muc pep 2(□), Muc pep 3 (■), Muc pep 4 (o), Muc pep 5 (●).

Figure 7. Inhibition of IB4 lectin binding to pig endothelial cells by mucin peptides. All peptides used at 5mM, using cytofluorograhic analysis. Inhibition calculated relative to no peptide control.

Figure 8. Inhibition of binding IB4 lectin and anti-Galα(1,3)Gal IgG to Galα(1,3)Gal-BSA by mucin peptides. Peptides at 5mM were examined in an Elisa for inhibition of IB4 (16μg/ml) (a) or anti-Galα(1,3)Gal IgG antibodies (75μg/ml) (b). Vertical axis shows peptides used, horizontal axis shows OD at 405 nm.

Figure 9. Inhibition of anti-MUC1 mAb by Gal pep 1. Varying concentrations of peptides (shown in mM on horizontal axis) were examined for ability to inhibit the binding of anti-MUC1 mAb to MOR5 cells using the cytoflurograph. Peptides used: Gal pep 1 (□), Muc pep 1 (♦)

Figure 10. Cell surface staining of COS cell transfection with MUC1 cDNA clone. (A) stained with VA1 mAb. (B) stained with 3E1.2 mAb. (C) stained with IB4 lectin.

Figure 11. Histological analsysis of malignant human tissue with IB4 lectin. Biotinylated IB4 lectin was used in an immunoperoxidase staining on formalin fixed and paraffin embedded tissue (A, B, C) or fresh frozen tissue (D,E,F). A: normal breast. B moderately differentiated infiltrating breast carcinoma. D: poorly differentiated infiltrating breast carcinoma. E moderately differentiated infiltrating breast carcinoma. F: adenocarcinoma of the colon. Original magnification x 200

Figure 12A & 12B Antibody titres in mice immusined with various preparations (see Figure) and tested on Gal peptide coated plate (Fig.12A) or on MUC1-peptide (CP^{13}-32 peptide) caoted plate (Fig.12B).

Figure 13 DBA 2^{++} mice were immunised three times intraperitoneally and mice were challenged with p815 $MUC1^{+}$ on P815 tumour cells. Mice immunised with Gal-KLH, Gal-KLH-FCA and Gal-KLH-mannan and challenged with p815 $MUC1^{+}$.

Figure 14 Direct CTL assay using p815 $MUC1^{+}$ (Tm2) or P815 targets. DBA/2 mice were immunised with MFP, or Gal-KLH.

Figure 15 CTL-assay using CTLs from DBA/2 Gal-KLH immunised mice on peptide (overlapping 9-mers spanning the MUC1 VNTR) pulsed P815 target cells.

Figure 16 CTL assay using CTLs from HLA-A2/K^{b} immunised mice with MFP or Gal-KLH. Target cells were either autologous spleen pHA-blast peptide (MUC1) at pulsed cells or HLA-A2 pHA-blast PBMC peptide (MUC1) pulsed.

Figure 17 Histological analysis of malignant human tissue with anti-Galα(1,3)Gal antibodies. Human anti-Galα(1,3)Gal antibodies used in an immunoperoxidase staining on formalin fixed and paraffin embedded tissue (A), and tested with human serum depleted of anti-Gal(1,3)Gal antibodies (B).

EXAMPLE 1 - RECOGNITION OF PEPTIDES BY ANTI-GALA(1,3)GAL ANTIBODIES

Materials and methods

Isolation of peptides from a peptide library

A random octamer library was constructed and screened by affinity purification [12] using the IB4 lectin (Sigman, St. Louis, MO.) from *Griffonia simplicifolia*, which binds to bind to the Galα(1,3)Gal [5]. After three rounds of screening phage clones that displayed specific binding to IB4 were amplified and their DNA sequenced.

Cells

The pig endothelial cell line, PIEC, was obtained from Dr, Ken Welsh (Churchill Hospital,

Oxford, UK). Peripheral blood lymphocytes (PBL) and erythrocytes (RBC) were obtained from fresh pig blood [14].

Synthesis of peptides

Peptides were synthesised using an Applied Biosystems Model 430A automated synthesiser (Foster City, Ca), based on the standard Merrifield solid phase synthesis method [ii], and were purified (to >90%) by reversed phase high performance liquid phase chromatography (Waters Associates, Milford, MA) on a C-8-Aquapore RP-300 column using a gradient solvent system of 0.1% aqueous trifluoroacetic acid/acetonitrile. All reagents for synthesis were purchased from Applied Biosystems.

Reagents

Normal human serum (NHS) was obtained from 10 health volunteers, pooled and heat inactivated at 56°C for 30 minutes before use. Human anti-Galα(1,3)Gal IgG antibodies were purified from the NHS by firstly fractionation on a Protein G sepharose column (Pharmacia LKB Biotechnololgy, Uppsala, Sweden), followed by affinity chromatography on Galα(1,3)Galβ(1,4)GluNAc conjugated glass beads (Syntesome, Princeton, NJ). FITC conjugated sheep anti-human IgM, sheep anti-mouse IgG and Horse radish peroxidase (HRP) conjugated sheep anti-human IgM or IgG were obtained from Silenus (Melbourne, Australia). HRP conjugated streptavidin was obtained from Amersham International (Amersham, UK). The anti-CD48 monoclonal antibody was produced at the Austin Research Institute [20]. The IB4 lectin was labelled with FITC or biotin [14,9]. Melibiose [Galα(1,6)Glc] and glucose were obtained from Sigma, and Galα(1,3)Gal, either free or coupled to BSA, was obtained from Dextra Laboratories (Reading, UK).

Serology

The binding of lectin or antibody to the surface of pig cells was detected by hemagglutination [14], cytotoxicity [21] or flow cytometry [14] using the FACSCAN flow cytometer (Becton Dickinson, Mountain View, CA).

Elisa

Relative affinities of the sugars or the peptides, for both IB4 lectin and human natural antibodies were calculated by comparing the molar concentration required to obtain 50% inhibition of the binding of antibody or lectin by sugars or peptides, using an ELISA: 50µl of Galα(1,3)Gal-BSA (Dectra Laboratories) at a concentration of 10µg/ml in 0.2M carbonate buffer pH 9.6 were added to the wells of an ELISA plate (Greiner, Frickenhausen, Germany), incubated at 37°C for 2 hours under humidifying conditions and non-specific binding sites were blocked with 2% BSA for 1 hour at 37°C. 50µl of either purified anti-Galα(1,3)Ga IgG or biotinylated IB4 lectin, was added to the wells, incubated for 45 minutes at 22°C, washed with PBS-0.05% Tween 20, and 50µl of the relevant HRP conjugate added and incubated for a further 45 minutes before washing and the addition of 50µl of substrate (2,2′ Azino-di-B-ethylbenzthiozoline (Zymed, San Francisco, CA)) and reading the OD_{405}

Results

Isolation of peptides that bind IB4 lectin

The peptide library, consisting of $1.4x10^9$ independent recombinant phage, was screened in three cycles of panning, elution and amplification against immobilised IB4. After the third cycle of panning, 9 randomly selected phage isolates displayed specific IB4 binding. The DNA from these clones was sequenced and the deduced peptide sequences are shown in Fig. 1 (N.B. one sequence, DGHWDSWL, appeared in three separate phage isolates). These peptides have the consensus sequence ArXXArZ, where Ar = W, F or Y, X is a small aliphatic or polar residue and Z is a branched aliphatic amino acid. One of these sequences, DAHWESWL (Gal pep 1), was synthesised for further studies and found to inhibit, by 50%, IB4 reaction with galactomannan (from *Cassia alata*) at a concentration of 5mM (not shown).

Peptide blocking of IB4 lectin and NHS hemagglutination of pig RBC

Inhibition of hemagglutination of pig RBC by IB4 using Gal pep 1 was consistently observed (Fig.2): complete inhibition of IB4 induced hemagglutination was observed using Gal pep 1 in the range of 5mM to 0.156mM, with no inhibition using the control peptide CD48 pep 1 (YTFDQKIVEWDSRKSKC) (Fig. 2A). Similarly, partial blocking of hemagglutination using NHS was observed with 5mM Gal pep 1 but not CD48 pep 1 (Fig. 2B).

Peptide blocking of the binding of IB4 lectin and NHS to pig endothelial cells and lymphocytes

Peptides were tested for inhibition of binding of IB4 to PIEC and pig PBL; Gal pep 1 completely inhibited the binding of IB4 to PIEC in the range of 5mM (Fig. 3A) to 0.625mM (now shown). The Gal pep 1 was then used to block the binding of human natural antibodies to PIEC: inhibition occurred at a concentration of 20mm (fig. 3b) But not when used at lower concentrations (data not shown). No inhibition was observed using CD48 pep 1 at a concentration of 20mM (Fig. 3A & B). Gal pep 1 also blocked the binding of IB4 with PBL at a peptide concentration of 5mM (Fig. 3C), whereas the control peptide had no effect. The specificity of these reactions was shown as Gal pep 1 had no effect on the binding of anti-CD48 monoclonal antibody to human PBL (data not shown).

Peptide blocking of the cytotoxicity of NHS on pig endothelial cells

Human cytotoxic antibodies directly damage pig endothelial cells in a pig-to-human xenograft, therefore the ability of Gal pep 1 to inhibit the cytotoxicity of human antibodies on PIEC *in vitro* was tested; Gal pep 1 inhibited the cytotoxicity of NHS (10mM to 2.5mM), whereas CD48 pep 1 had no effect (Fig.4).

Relative "affinities" of Gal pep 1 and α-galactosyl sugars for IB4 lectin or anti-Galα(1,3)Gal antibodies

An Elisa was established to calculate the relative "affinity" of the Gal pep 1 for the IB4 lectin and for human anti-Galα(1,3)Gal antibodies, and to compare these with the affinities for α-galactosyl sugars. Biotinylated IB4 lectin and purified anti-Galα(1,3)Gal IgG antibodies were titered on Galα(1,3)Gal-BSA, and for the blocking experiments were used at two dilutions less than that required to give 50% of the maximum OD_{405} reading. The results of inhibition of either the IB4 lectin or pure anti-Galα(1,3)Gal IgG antibodies with glucose, melibiose, Galα(1,3)Gal or Gal pep 1 are shown in Fig. 5; the IB4 lectin (Fig 5 A & B) or pure anti-Galα(1,3)Gal IgG antibodies (Fig. 5 C & D) where inhibited by melibiose and Galα(1,3)Gal and Gal pep 1 but not glucose or CD48 pep 1. The concentration of peptide or sugar which inhibited the binding of antibody or lectin by 50% was calculated as a measurement of relative affinity (Table 1): 0.3mM Gal pep 1 inhibited the binding of IB4 compared with 0.3mM melibiose or <0.03mM Galα(1,3)Gal, 10mM

Gal pep 1 inhibited the binding of the anti-Galα(1,3)Gal IgG compared with 0.125mM-0.3mM melibiose and 0.03mM Galα(1,3)Gal. Neither the CD48 pep 1 nor glucose had any effect on the binding of antibody or lectin.

EXAMPLE 2 - RECOGNITION OF HUMAN MUCIN PEPTIDES BY ANTI-GALα(1,3)GAL ANTIBODIES

Materials and methods

Cells

The pig EC cell line (PIEC) was obtained from Dr Ken Welsh (Churchill Hospital, Oxford, UK). MUC1+3T3 cells (MOR5 cells), produced by introducing cDNA encoding human MUC1 into murine 3T3 cells, were obtained from Dr Daniel Wreschner, (Tel Aviv University, Ramat Aviv, Israel).

Antibodies, lectin and saccharides.

Normal human serum (NHS) was obtained from 10 healthy volunteers, pooled and heat inactivated at 56°C for 30 minutes before use. Purified human anti-Galα(1,3)Gal IgG antibodies were isolated from NHS by firstly fractionation of IgG on a Protein G Sepharose column (Pharmacia LKB Biotechnology, Sweden), followed by affinity chromatography on Galα(1,3)Galβ(1,4)GluNAc coated glass beads (Syntesome, NJ). FITC conjugated sheep anti-human IgM, sheep anti-mouse IgG and horse radish peroxidase (HRP) conjugated sheep anti-human IgM or IgG were obtained from Silenus Laboratories Pty. Ltd., Australia. HRP conjugated streptavidin was obtained from Amersham International, UK. The BC2 mAb, which recognises the APDTR epitope of the human MUC1 molecule, is described elsewhere [23,24]. The IB4 lectin from *Griffonia simplififolia*, which binds to Galα(1,3)Gal [22], was obtained from Sigma, USA and was labelled with FITC or biotin [14,9]. Melibiose (Galα(1,6)Glc) and glucose (Sigma) were >99% pure. The Galα(1,3)Gal disaccharide, either free or coupled to BSA, was obtained from Dextra Laboratories, UK.

Peptide synthesis

Peptides were synthesised using an Applied Biosystems Model 430A automated synthesiser

(Applied Biosystems, USA) based on the standard Merrifield solid phase synthesis method [25]. All reagents for synthesis were purchased from Applied Biosystems. Crude peptides were purified by reversed phase high performance liquid phase chromatography (HPLC) (Waters Associates, USA) on a C-8-Aquapore RP-300 column using a gradient solvent system of 0.1% aqueous trifluoroacetic acid/acteonitrile. The purity of synthetic peptides was >90% as judged by HPLC analysis. Peptides were dissolved in phosphate buffered saline (PBS) prior to use in the serological assays. The peptides used in this study are listed in Table 1.

Serological assays

Peptides or carbohydrates were examined cytofluorographically for their ability to inhibit antibody/lectin binding to the cell surface using a FACSCAN flow cytometer (Becton Dickinson, USA)[20]: 25µl of inhibitor was mixed with 25µl of antibody of lectin and incubated at 22°C for 3 hours (peptides) or at 4°C for 16 hours (carbohydrates)[14], prior to addition of appropriate targets. An Elisa assay was used to calculate the relative affinities of the sugars or the peptides for both IB4 lectin and antibodies, and were defined as the molar concentration of inhibitor giving 50% inhibition of the maximal binding of lectin or antibody.

Transfection studies

COS cells transfection experiments were performed using DEAE Dextran [13] and a cDNA clone encoding human MUC1 [6], or a cDNA clone encoding the porcine α(1,3)galactosyltransferase [16]. As additional controls, COS cells were also transfected with the vector lacking an insert (mocj transfections). Indirect immunofluorescence was performed on cell monolayers in 6 well tissue culture plates using fluoresceinated IB4 lectin (which binds only to Galα(1,3)Gal), or anti-MUC1 monoclonal antibodies, 3E1.2[4] and VA1[28] and immunopurified sheep anti-mouse IgM or IgG to detect antibody binding.

Histological analysis

Fresh or formalin fixed human tissue was incubated with biotinylated IB4 lectin (at 100µg/ml) for 50 min at 22°C, washed, incubated with streptavidin-HRP for one hour, followed by diaminobenzidine (Amershal International, UK) at 1.5mg/ml with 0.05% H_2O_2 for 5 min, prior

to the removal of excess substrate by washing in running tap water for 3 min. The sections were counterstained with haematoxylin, mounted and examined microscopically. Tissues staining was graded independently by two investigators and scored as: 0 (no staining) to 4 (very strong staining).

Results

Our previous studies had shown that:-

(a) natural human antibodies of the IgM and IgG classes bound to a single epitope in the pig, Galα(1,3)Gal (IB4 lectin binds the same epitope) [15,16,17];

(b) the antibodies and IB4 lectin could also bind to the synthetic peptide DAHWESWL. During these studies and testing the specificity of peptide binding, it was apparent that the anti-Galα(1,3)Gal reagents (antibodies or IB4 lectin) could also bind to other peptides - notably those of the protein core of several mucins.

Blocking IB4 binding to Galα(1,3)Gal expressing pig cells by mucin deprived peptides

Muc pep 1, derived from the MUC1 VNTR, could block the binding of IB4 lectin to the cell surface of PIEC cells (Fig. 6); there was almost complete inhibition of binding to a concentration of 0.125mM - indeed, the inhibition by the MUC1 VNTR peptide was greater than that found with the previously identified IB4 lectin binding peptide, Gal pep 1 (Fig. 6a). When other peptides derived from the VNTR region of MUC 1 were examined (see Table 2 for sequences), complete inhibition was observed with Muc pep2 and Muc pep 3, and partial inhibition with Muc pep 4 and Muc pep 5 (Fig 6b). The data can be reformatted as % inhibition at 5mM to show comparative binding (Fig. 7), with the same trend was noted at 2 other concentrations (data not shown). Muc pep6, derived from sequence amino terminal to the VNTR, showed partial inhibition; by contrast Muc pep 7, derived from the same region, did not (Fig. 7). Muc pep 8, derived from sequence carboxy terminal to the VNTR, also inhibited IB4 binding to PIEC cells (Fig. 7). Peptides derived from the VNTR regions of other human mucin molecules showed variable results: Muc pep 9, derived from the VNTR region of MUC 2, did not inhibit binding, whereas both Muc pep 10 and Muc pep 11, derived from the VNTR region of MUC3 and MUC4 respectively, inhibited IB4 binding (Fig 7). Thus, peptides derived from the VNTR and

elsewhere in MUC1 can inhibit the interaction of IB4 with its ligand, Galα(1,3)Gal. It should be noted that these peptides have been used to produce anti-mucin mAbs which specifically recognise the immunogenic peptide and there were no cross-reactions of the antibodies with other peptides, although the sequences are similar [23].

Inhibition of binding of IB4 and anti-Galα(1,3)Gal antibodies to Galα(1,3)Gal by mucin peptides.

Mucin peptides were also examined for their ability to block the binding of IB4 lectin and anti-Galα(1,3)Gal IgG to the oligosaccharide epitope Galα(1,3)Gal-BSA bound in a microplate using an Elisa test (Fig.8). At a peptide concentration of 5mM, complete inhibition of binding of IB4 was observed with peptides Muc pep 1, Muc pep 3, Muc pep 4, Muc pep 5, Muc pep 6 and Muc pep 11 (Fig.8a). By contrast Muc pep 7 and Muc pep 9 gave no inhibition of binding. Gal pep 1 inhibited as previously described, and the control peptides CD48 pep 1, CD4 pep 1 and TNF pep 1 did not inhibit IB4 binding (Fig. 8a).

In accord with the inhibition results obtained previously with human antibodies, a higher concentration of Gal pep 1 was required to inhibit the binding of the purified human anti-Galα(1,3)Gal IgG antibody than with the IB4 lectin (Fig. 8b). The three peptides tested from the VNTR region of human MUC1:- Muc pep 1, Muc pep 3 and Muc pep 11 inhibited the binding of anti-Galα(1,3)Gal IgG (Fig. 8b), with Muc pep 4 showing partial inhibition. The three control peptides (CD48 pep 1, CD pep 1 and FcR pep 1) had no effect (Fig 8b).

Relative affinities of mucin peptides for Galα(1,3)Gal.

Elisa results were used to calculate the relative affinity of the mucin peptides for the IB4 lectin and for human anti-Galα(1,3)Gal antibodies, and to compare these with the affinity for α-galactosyl sugars. Biotinylated IB4 lectin and purified anti-Galα(1,3)Gal IgG antibodies were titered and for the affinity experiments were used at two dilutions less than that required to give 50% of the maximum OD_{405} reading; the concentration of peptide or sugar which inhibited the binding of antibody or lectin by 50% was calculated as a measurement of relative affinity (Table 3). The studies showed that 0.3mM Gal pep 1 inhibited the binding of IB4 compared with

<0.03mM Galα(1,3)Gal; 0.078 mM Muc pep 1, 0.625 mM Muc pep 3, 0.975 mM Muc pep 4, w.5 mM Muc pep 5, 1.25 mM Muc pep 6 and 0.156 mM Muc pep 11 inhibited the binding of IB4, 0.03mM Galα(1,3)Gal inhibited the binding of the anti-Galα(1,3)Gal IgG compared with 2.5 mM pep 1, 3.75 mM Muc pep 3, 5 mM Muc pep 4 and 2.5 mM Muc pep 11 (Table 3). All the mucin peptides inhibited at a lower concentration that Gal pep 1 (10 mM). Neither the CD48 pep 1, Scram pep 1 (a random peptide of Gal pep 1 sequence), nor glucose had any effect on the binding of antibody or lectin.

Blocking of the binding of anti-mucin 1 mAb to mucin 1 by Gal pep 1.

To extend these observations, the ability of Gal pep 1 to inhibit anti-MUC1 mAb, BC1, was examined. The BC1 mAb has been previously shown to specifically recognise the APDTR sequence of MUC1 VNTR [23]. The binding of BC1 to MUC1 + 3T3 cells was inhibited by Gal pep 1 down to a concentration of 0.156 mM (Fig. 9), in a similar fashion to Muc pep 1. These results show that, despite the lack of amino acid sequence similarity, the Muc pep 1 and Gal pep 1 peptides are equally recognised by the mAb, suggesting recognition of a secondary or tertiary structure.

Binding of IB4 to COS cells expressing MUC1 on the cell surface

We have previously shown that COS cells, derived from Old World monkeys, do not react with the IB4 lectin (ie. they do not express Galα(1,3)Gal), and that the Galα(1,3)Gal epitope can be expressed on the surface of these cells only after transfection with the porcine or mouse α(1,3)galactosyltransferase cDNA clones [16,17]. To examine whether expression of human MUC1 leads to IB4 binding, transfection of COS cells with the full length human MUC1 cDNA clone was performed. MUC1 could be detected on the COS cell surface by binding of the anti-MUC1 mAbs (Fig.10 a&b), these cells were also reactive with the IB4 lectin (Fig. 10c). Thus native MUC1 polypeptide encodes amino acid sequences to which IB4 can bind. When COS cells transfected with the porcine α(1,3)galactosyltransferase cDNA clone were examined from anti-MUC1 mAb binding, weak staining was observed (data not shown).

Histological analysis of IB4 reactivity of human tissue

As IB4 and anti-Galα(1,3)Gal antibodies bind to mucin peptides, histological studies with

biotinylated IB4 lectin on human normal or malignant tissues were performed. Using formalin fixed tissue, one of the normal breast tissues were reactive with the IB4 lectin, compared with 3 of 13 breast cancers which were reactive; 5 formalix fixed colon cancer samples did not bind IB4-biotin. The results with fresh tissue samples showed stronger binding of the IB4 lectin - 0/3 normal breast tissue samples tested bound IB4 lectin, whereas 4/4 the breast cancer tissue were positive. With colon cancer tissues 3/7 were reactive, compared to 1/6 of the normal tissues. Representative samples of the histological analysis of human malignant tissues are shown (Fig. 11). Formalin fixed normal breast tissue which was not reactive with IB4-biotin, (Fig. 11a) infiltrating ductal breast carcinoma tissue (Figs. 11 b,c), where cytoplasmic staining with IB4-biotin is clearly shown (Fig. 11b) and cell surface staining of the lumen and glandular cells (Fig 11c). Binding of the IB4 lectin was also demonstrated on fresh frozen human malignant tissue. Poorly differentiated, infiltrating ductal breast carcinoma tissue shows strong cytoplasmic staining with IB4-biotin (Fig. 11d), whereas staining of secretions in the lumen of glandular cells can be seen in a sample of moderately differentiated, infiltrating ductal breast carcinoma tissue (Fig. 11e). There is also strong staining of secretions and the cytoplasm of frozen sample of colon tissue (Fig. 11f).

Similar results to those obtained with the IB4 lectin were also found with purified human anti-Galα(1,3)Gal antibodies (Fig. 17A). Strong cytoplasmic and cell surface staining was noted in most samples - in those with luminal secretion these were also positive (Fig. 17A). It is important +to note that the staining was almost completely eliminated by absorbing the human serum with Galα(1,3)Gal beads so it no longer contained anti-Galα(1,3)Gal antibodies (Fig. 17B). Both of these studies clearly indicate that the staining of breast cancer was due to anti-Galα(1,3)Gal antibodies.

EXAMPLE 3 - GAL PEP 1 AND MUC1 RESPONSE AND ANTI-TUMOUR ACTIVITY IN MOUSE MUC1$^+$ TUMOURS

BALB/c or DBA/2 ($H2^d$) mice were immunised with the DAHWESWL peptide (Gal pep 1) coupled to KLH or with MUC1 fusion protein conjugated to oxidised mannan; 3 injections intraperitoneally (IP) were given weekly. It is important to note that mannan-MUC1 produces

exceedingly good CTL based immune responses with protection from challenge with large numbers ($50x10^6$) of the tumour cells. The oxidised mannan-MUC1 gives high affinity CTLs, and little antibody, which are typical T_1 responses and such responses were confirmed herein (Fig. 12A). We noted that the DAHWESWL-KLH immunised mice challenged with MUC1$^+$ tumour had similar degrees of protection, which was entirely specific for MUC1$^+$P815 cells - there was no immunisation effect against P815 alone or other tumours (Fig. 12B&14) i.e. the anti-tumour immunity appears to be directed to the MUC1$^+$ cells.

The inventors previously showed that, in mice immunised with MUC1 peptide (not linked to mannan) had some protection evidenced by smaller tumours which disappeared earlier than in the controls. In the mannan-MUC1 immunised mice there was little or no tumour growth apparent at all, i.e. the mice are entirely protected by this mode of immunisation. Similarly, mice immunised with DAHWESWL-KLH had little or no tumour growth, i.e. the mice appeared to be immunised to the same extent with the DAHWESWL peptide as with the mannan-MUC1 peptide. The effect was clearly specific as DAHWESWL immunised mice had normal growth of P815 cells (Fig. 13). Two other MUC1$^+$ tumour cell lines (MUC1$^+$ 3T3 or MUC1$^+$ P815) were used in protection experiments and a similar degree of protection was noted (not shown).

It was next determined whether the mice carrying established MUC1$^+$ tumours could be immunised with the DAHWESWL peptide. It was clearly noted that a rapid reversal of tumour growth occurred (not shown) and this was specific for MUC1.

The nature of the immune response to DAHWESWL was further examined. The studies were performed in the knowledge that MUC1 peptides induce Class I restricted CTL responses - the MUC1 epitopes have been mapped and although do not contain typical K^d, D^d or L^d binding motifs they satisfactorily bind H-2 class I molecules with high affinity The DBA/2 mice immunised with DAHWESWL peptide produced anti-DAHWESWL and anti-MUC1 antibodies and CTLs. In addition, anti-MUC1 CTLs were also produced and appeared to have the same or greater activity than those produced by MUC1 mannan conjugates (Fig. 14). Clearly, DAHWESWL peptide could associate with Class I H2 molecules.

To determine which anti-MUC1 epitopes were reacting with the anti-DAHWESWL CTLs, epitope mapping studies were performed using 9-mer peptides each primer peptide differing from the preceding by one amino acid so that the whole 20 amino acid VNTR sequence could be scanned. The results were clear (Fig. 15), only the peptides containing the sequence SAPDTRPAP or APDTRPAPG could lead to target cell lysis. There was no lysis of target cells with the other 18 peptides from the VNTR (Fig. 15) providing an appropriate specificity control. Thus, DAHWESWL immunised mice could induce CTLs which react with precisely the same SAPDTRPAP/APDTRPAPG sequences which we have previously shown to bind to H-2D^d and H-2L^d class I molecules respectively. In addition, the same sequences can be recognised in H-2K^b mice after immunisation with DAHWESWL.

However, these sequences cannot be recognised on HLA-A2 molecules, where, to recognise MUC1-HLA-A2 complexes requires immunisation with DLHWASWV or a related sequence derived from the provided consensus sequence.

Molecular modelling studies were performed to determine whether the MUC1 and DAHWESWL sequences were capable of conforming to the same shape. The modelling studies were done with the knowledge obtained from the crystallisation with H-2D^d and H-2L^d. By computer modelling, H-2D^d and H-2L^d molecules were modelled with DAHWESWL/SAPDTRPAP and DAHWESWL/APDTRPAPG respectively and it was clear that the DAHWESWL/SAPDTRPAP/APDTRPAPG peptides are capable of assuming the same shape - although at this point crystallisation with class I molecules containing the peptides will be required to confirm this. It should be noted that DAHWESWL and (S)APDTRPAP(G) peptides have a completely different amino acid sequence, thus shape is important.

It was next investigated whether the DAHWESWL peptide be presented by HLA-A2 could immunise for HLA-H2 presented MUC1 peptides. The inventors had previously found that (S)APDTRPAP(G) peptide sequence can also be presented by HLA-A2 (in addition to H-2D^d and H-2L^d as described above). However, HLA-A2/K^b mice immunised with DAHWESWL-KLH could not generate CTLs which reacted with MUC1 HLA binding peptides when in the HLA-A2 class I groove (Fig. 16), although mouse autologous PHA blast targets were positive

(restricting element here is K^b). This was not surprising and clearly demonstrates that the shape of the DAHWESWL peptide in the H-2^d groove is determined both by the peptide sequence and also by the class 1 sequence. Thus the DAHWESWL peptide gives highly specific immune responses which appear to be directed to the human MUC1 peptide presented by MHC class I molecules. However, we now predict that DLHWASWV will protect mice/humans against MUC1 positive tumours suggesting that the "W" molecules which are exposed and "stick out" are important in the recognition of the sequence by T-cells.

Thus using the examples provided for the Class I molecules H-$2D^d$, H-$2L^d$, H-$2K^b$ and HLA-A2 we can, by using the known peptide sequence, the known consensus sequences, and computer modeling, come up with mimicking peptide sequences which can immunize against MUC1 peptides presented by Class I molecules. Based on these examples, peptides binding to other Class I molecules of humans can be deduced.

It is to be recognised that the present invention has been described by way of example only and that modifications and/or alterations thereto which would be obvious to a person skilled in the art on the basis of the teaching herein are considered to be within the scope and spirit of the present invention as defined in the appended claims.

Table 1. Relative affinities of peptides and carbohydrates for IB4 and pure anti-Galα(1,3)Gal IgG.

Inhibitor	I_{50}[a] (mM) IB4[b]	anti-Galα(1,3)Gal IgG[c]
Carbohydrate:		
Galα(1,3)Gal	<0.03	0.03
Melibiose	0.3	0.3-0.125
Glucose	>20	>20
Peptide:		
Gal pep 1	0.3	10
CD48 pep 1	>20	>20

a. I_{50} is the concentration of peptide or sugar required to give 50% inhibition of antibody or lectin binding.

b. Biotinylated IB4 lectin used at a final concentration of 6.25 µg/ml.

c. Anti-Galα(1,3)Gal IgG used at a final concentration of 87µg/ml.

Table 2 Sequences of peptides used in this study

Peptide	Sequence	Description	Residues	Reference
Gal pep1	DAHWESWL			
CD48 pep1	YTFDQKIVEWDSRKSKC	human CD48		
CD4 pep1	TECKHKKGKVVSGKVLSY	murine CD4	133-149	
FcR pep1	RYHHYSSNFSIPKANHSHSGDYYCKGSL	MURINE FCRIIβ2	144-157	
TNF pep1	LSGVRFSAARTAHPLPQKH	MURINE TNFβ		
Muc pep1	CPAHGVTSAPDTRPAPGSTAP	human Muc1 VNTR	13-32	
Muc pep2	PAHGVTSAPDTRPAPGSTAP	human Muc1 VNTR	13-32	
Muc pep3	PDTRAPGSTAPPAHGVTSAPDTR	human Muc1 VNTR	1-24	
Muc pep4	APDTRPAPGSTAPPAH	human Muc1 VNTR	A-1-15	
Muc pep5	PAPGSTAPPAHGVTSA	human Muc1 VNTR	5-20	
Muc pep6	TGSGHASSTPGGEKETSAQRSSVP	human Muc1 NH2 to VNTR	31-35	
Muc pep7	RSSVPSSTEKNAVSMTSSVL	human Muc1 NH2 to VNTR	51-70	
Muc pep8	TGFNQYKTEAASRVNL	human Muc1 COOH to VNTR	408-423	
Muc pep9	KYPTTTPISTTTMVTPTPTPTGTQTPTTT	human Muc2 VNTR		
Muc pep10	CHSTPSFTSSITTTETTS	human Muc3 VNTR		
Muc pep11	TSSASTGHATPLPVTP	human Muc4 VNTR		
Scram pep1	WEADLHWS	scrambled Gal pep1		

Table 3 Relative affinity of peptides and sugars for IB4 lectin and pure anti-Gala(1,3)Gal IgG.

Inhibitor	I_{50}[a] (mM)	
	IB4 [b]	Anti-Galα(1,3)Gal[c]
Galα(1,3)Gal	<0.03	0.03
Glucose	>20	>20
Gal pep 1	0.3	10
CD48 pep1	>20	>20
Muc pep1	0.078	2.5
Muc pep3	0.625	3.75
Muc pep4	0.975	5
Muc pep5	2.5	ND[d]
Muc pep6	1.25	ND
Muc pep11	0.156	2.5
Scram pep1	>20	>20

a I_{50} is the concentration of peptide or sugar required to give 50% inhibition of antibody or lectin binding.

b Biotinylated IB4 lectin used at a final concentration of 6.25µgs/ml.

c Anti-Galα(1,3)Gal antibody (IgG) at a final concentration of 87µgs/ml.

d. ND = not determined

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Cytotoxic T lymphocyte precursor cell (CTLp) frequency determinations: described in I. Lefkovits and H. Waldmann, *Immunology Today* 5, 265 (1984);
C. Taswell, *J. Immunol.* 126, 1614 (1981); S. Fazekas DE ST.Groth. *J. Immunol. Methods* 49, R11 (1982)

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CLAIMS

1. A cancer vaccine comprising a peptide which mimicks MUC1 or other cancer peptides, and one or more pharmaceutically acceptable carrier or diluent, optionally in association with an appropriate carrier peptide or another therapeutic agent.

2. The vaccine as claimed in claim 1 wherein said peptide comprises from between 5 and about 200 amino acids and includes the consensus sequence. ArXXArZ wherein:

Ar is the same or different and is selected from tryptophan (W), phenylalanine (F) or tyrosine (Y);

X is the same or different and is a small aliphatic or polar amino acid;

Z is a branched aliphatic amino acid.

3. The vaccine as claimed in either claim 1 or claim 2 wherein said peptide includes one or more of the following sequences:

DGHWANWV
DGNWAIYV
DADWAGFI
DAHWESWL
DGHWDSWL
VSTFDSWL
GTSFDDWL

4. The vaccine as claimed in any one of claims 1 to 3 wherein the peptide is DAHWESWL

5. A method of treatment of a human patient suffering from, or prone to suffer from cancer, which comprises administering to said patient an effective amount of a cancer vaccine

comprising a peptide which mimicks MUC1 or other cancer peptides, and optionally one or more pharmaceutically acceptable carrier or diluent, optionally also in association with one or more appropriate carrier peptides or another therapeutic agent.

6. The method as claimed in claim 5 wherein said cancer is an adenocarcinoma.

7. The method as claimed in either claim 5 or claim 6 wherein said peptide comprises from 5 to about 200 amino acids and includes the consensus sequence ArXXArZ wherein;

Ar is the same or different and is selected from tryptophan (W), phenylalanine (F) or tyrosine (Y);

X is the same or different and is a small aliphatic or polar amino acid;

Z is a branched aliphatic amino acid.

8 The method as claimed in any one of claims 5 to 7 wherein said peptide includes one or more of the following sequences;

DGHWANWV
DGNWAIYV
DADWAGFI
DAHWESWL
DGHWDSWL
VSTFDSWL
GTSFDDWL

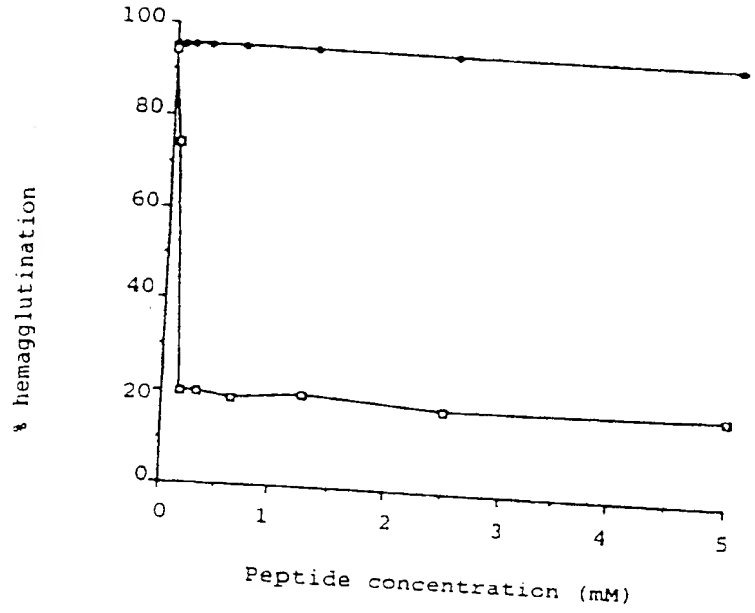
9. The method as claimed in any one of claims 5 to 8 wherein the peptide is DAHWESWL.

FIG. 1

DGHWANWV
DGNWAIYV
DADWAGFI
DAHWESWL
DGHWDSWL
VSTFDSWL
GTSFDDWL

FIG. 2

A


100
80
60
40
20
0
% hemagglutination
0
1
2
3
4
5
Peptide concentration (mM)

B

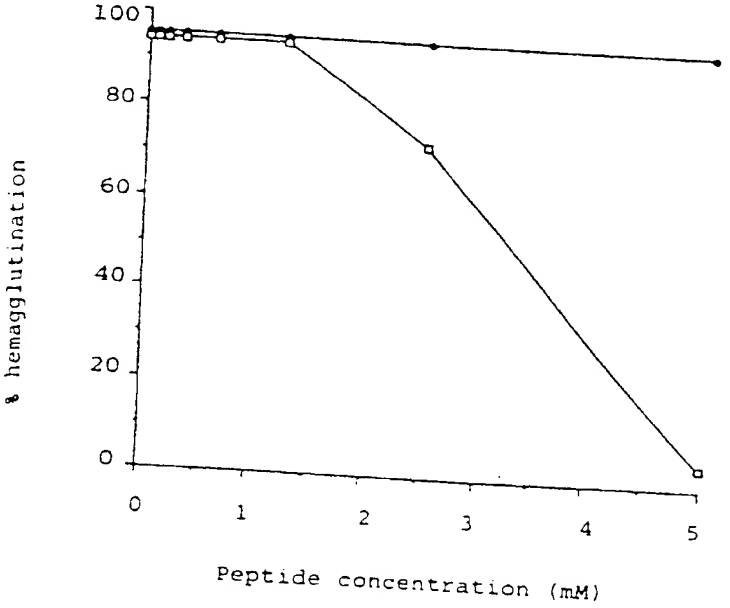

100
80
60
40
20
0
% hemagglutination
0
1
2
3
4
5
Peptide concentration (mM)

FIG. 3

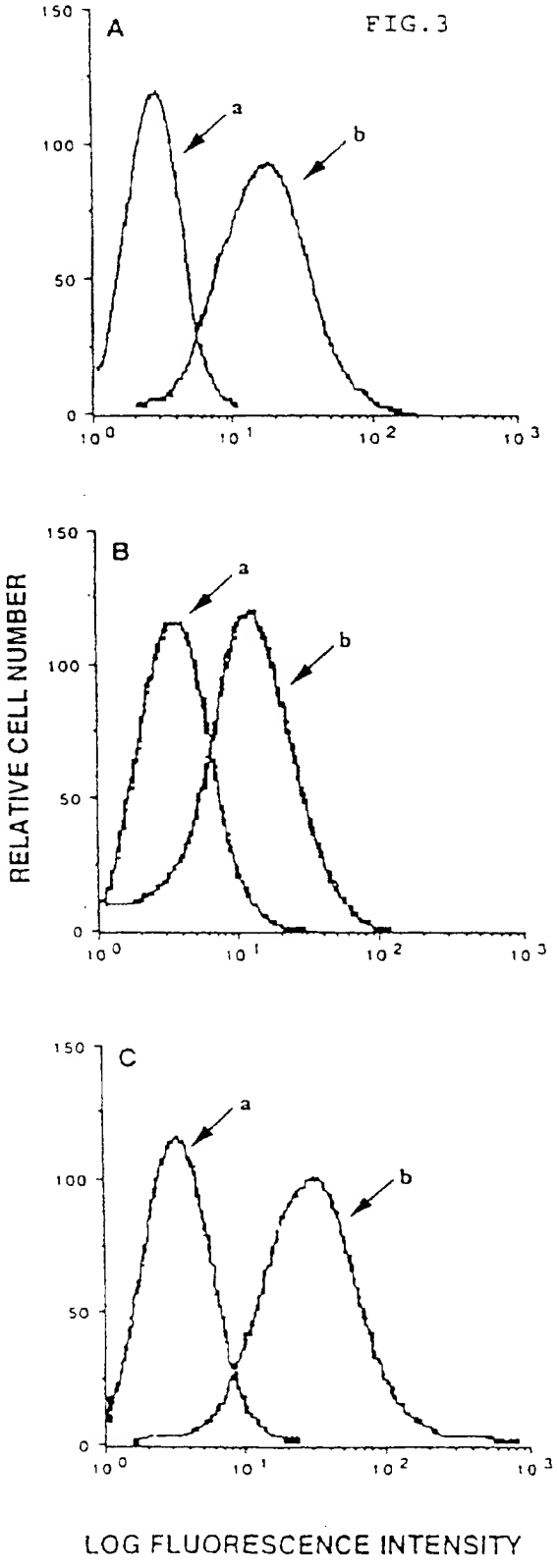


FIG. 4

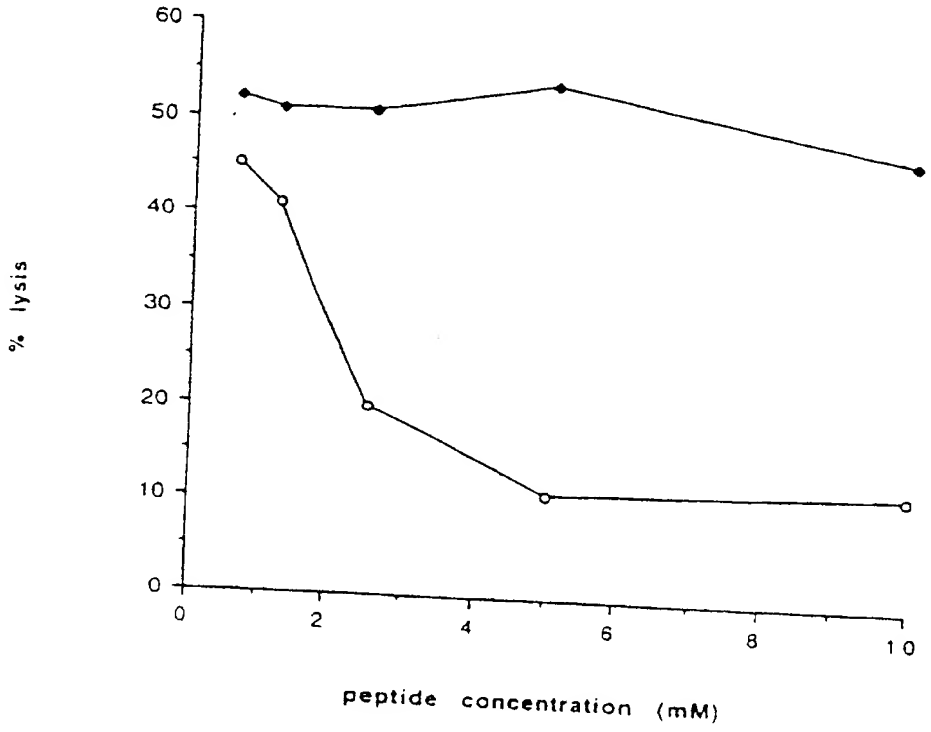


FIG.5

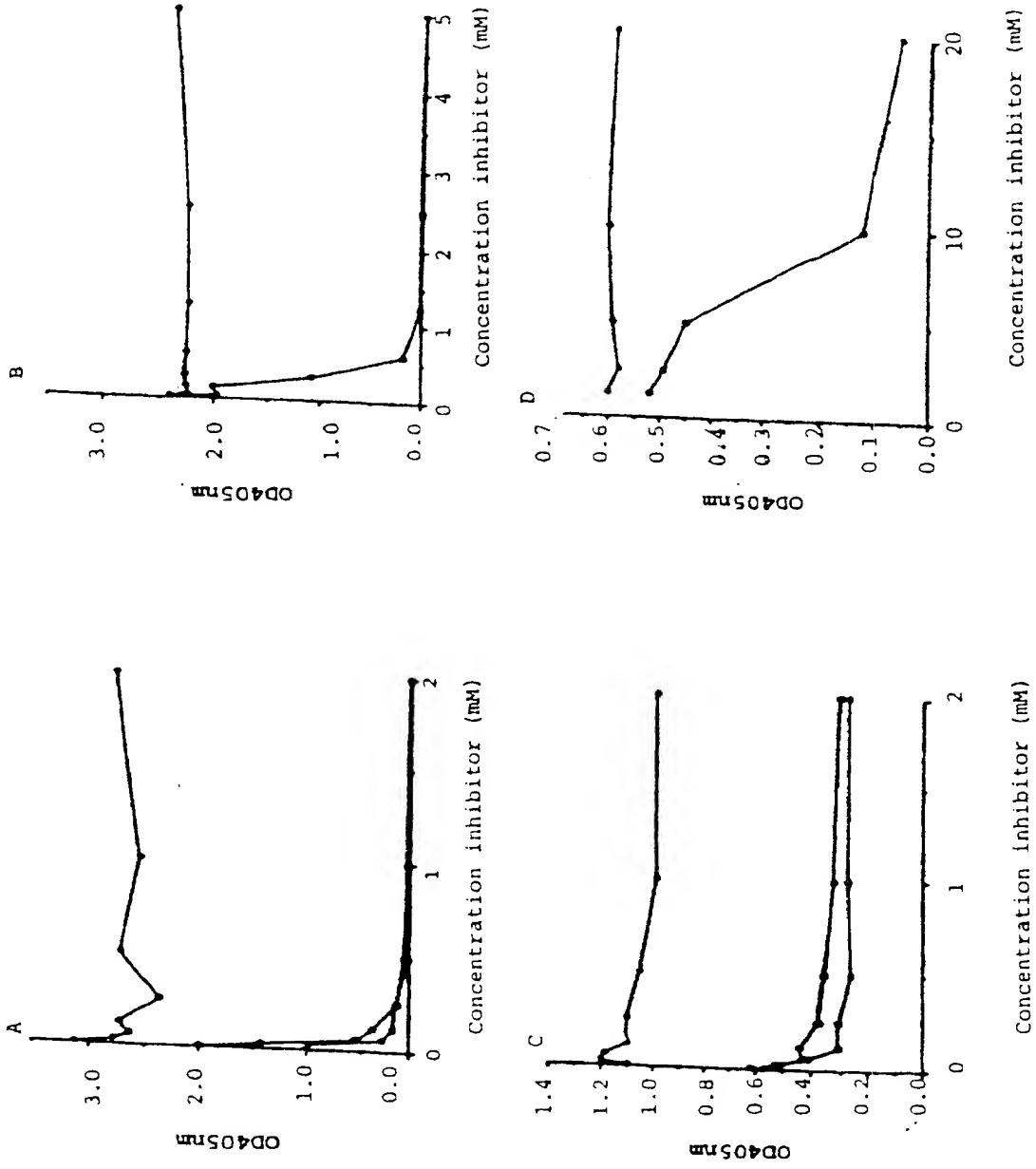
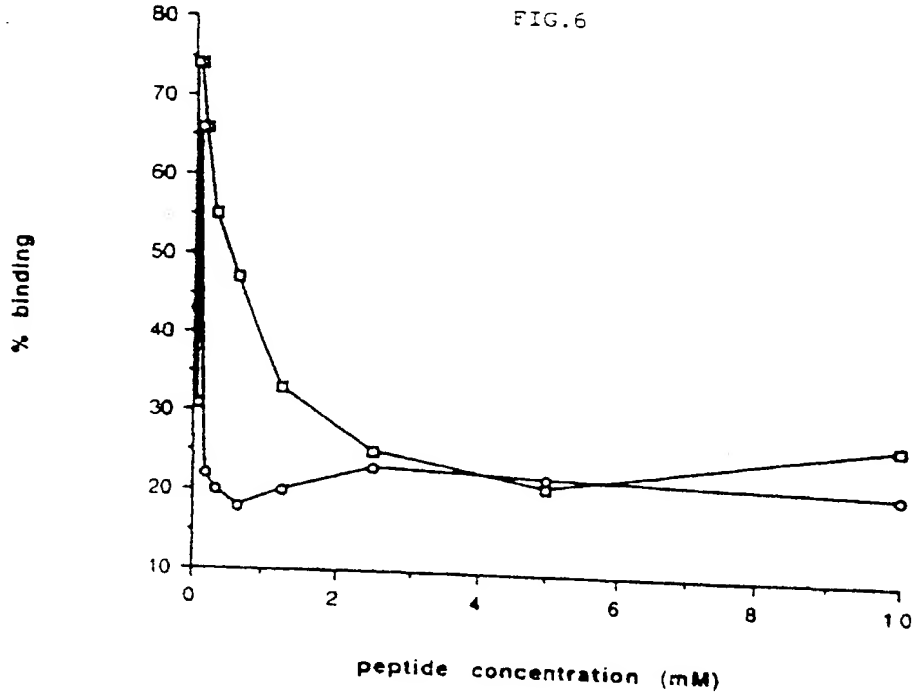


FIG.6

a



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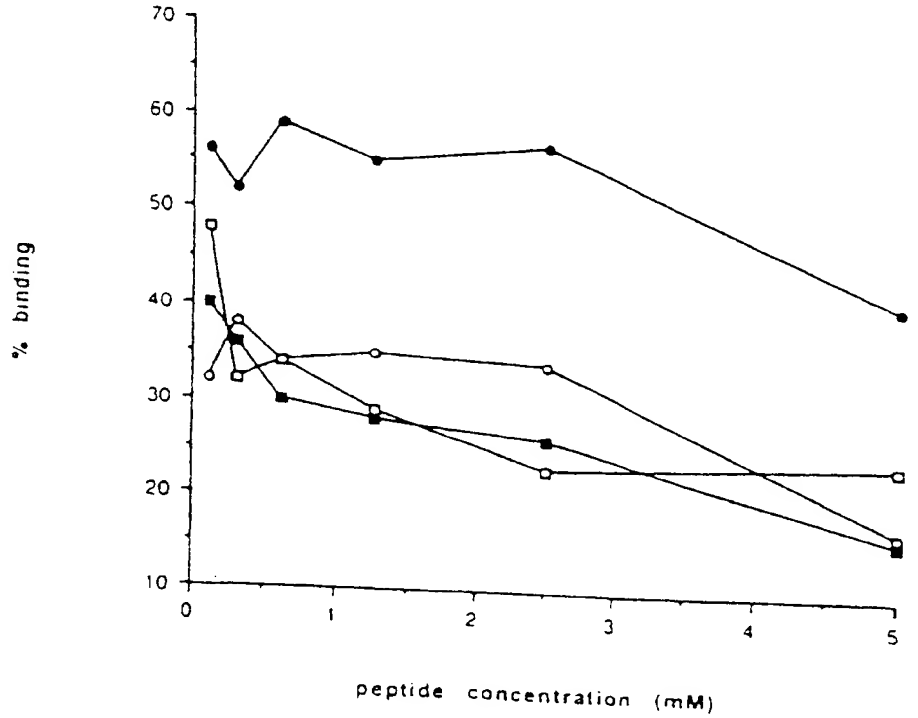
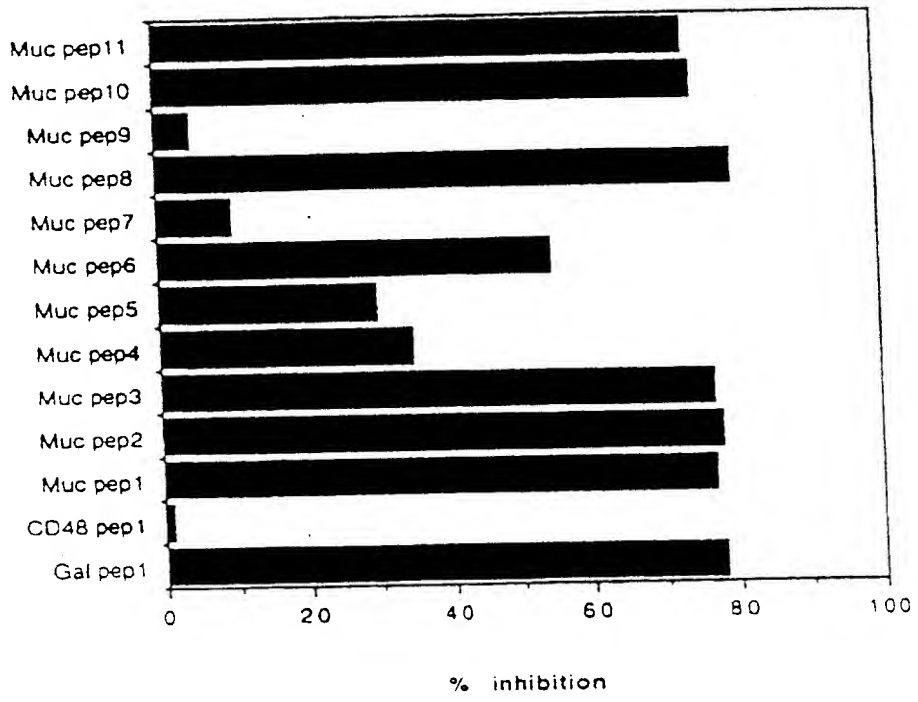


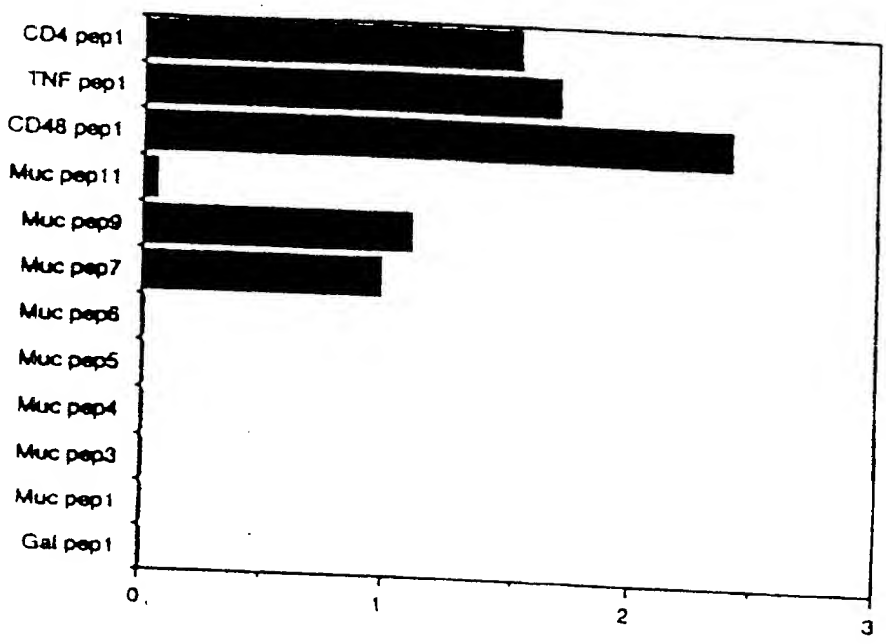
FIG.7



8/17

FIG.8

a



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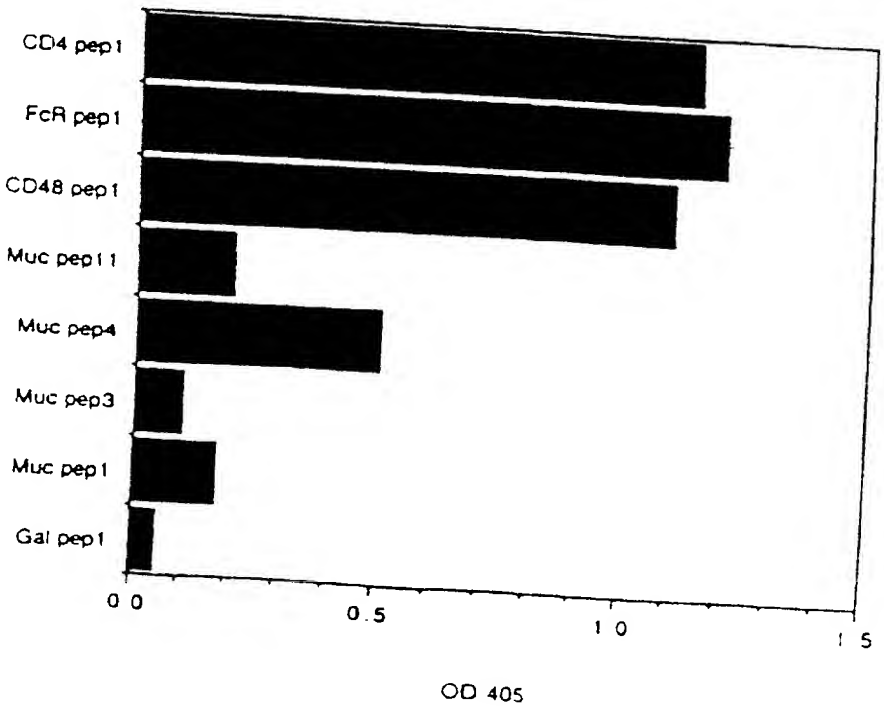


FIG. 9

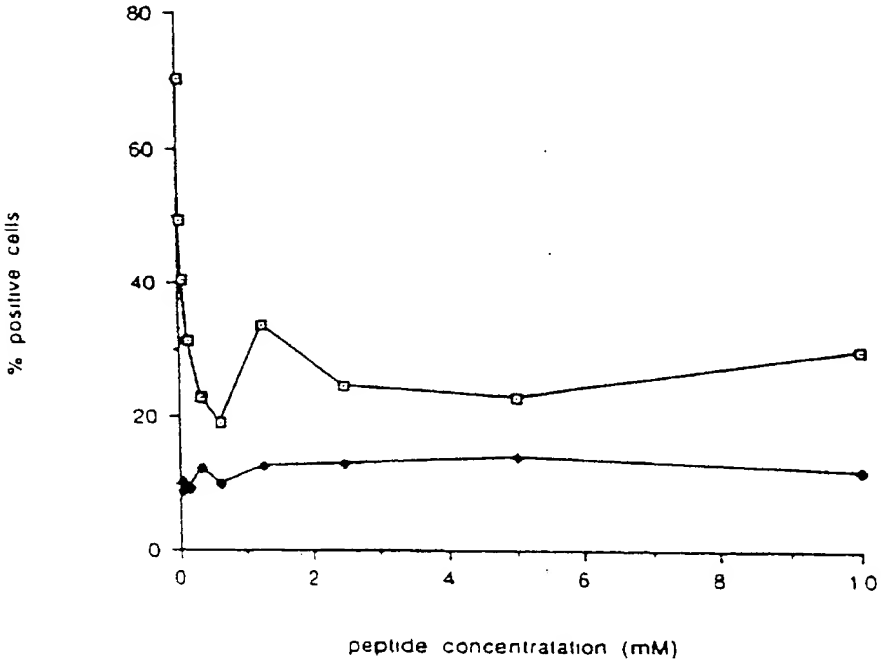
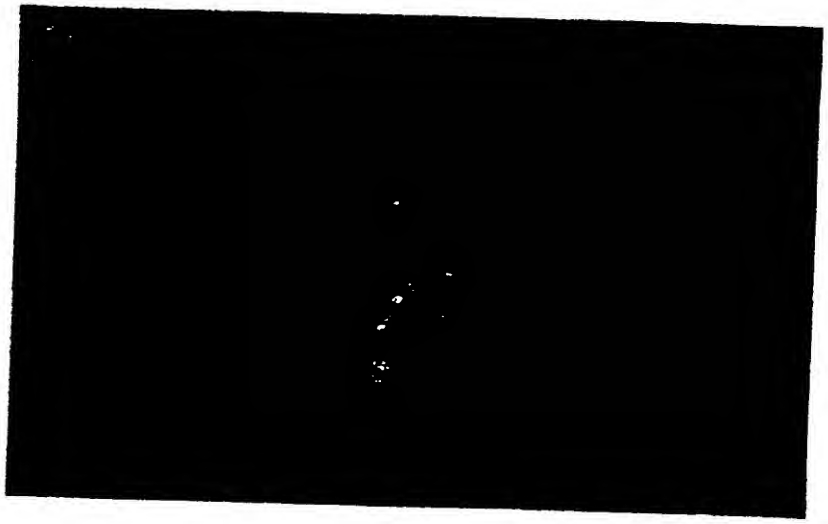
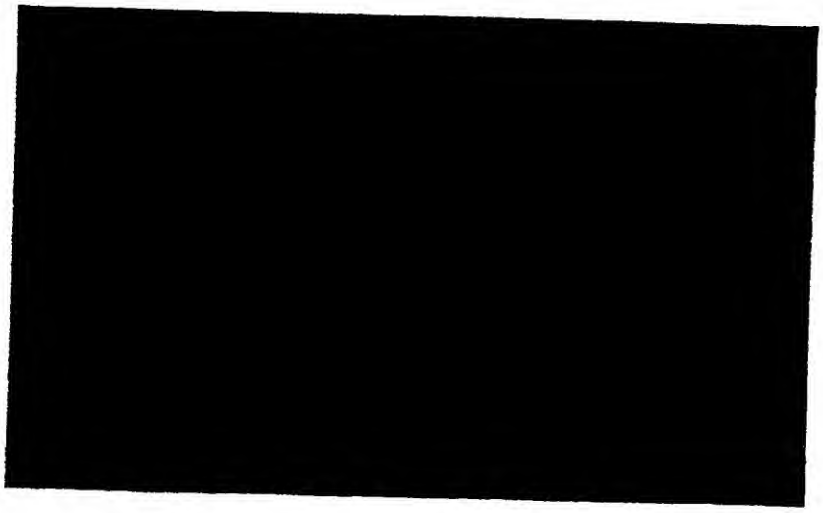


FIG. 10

(A)



(B)



(C)

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FIG. 11

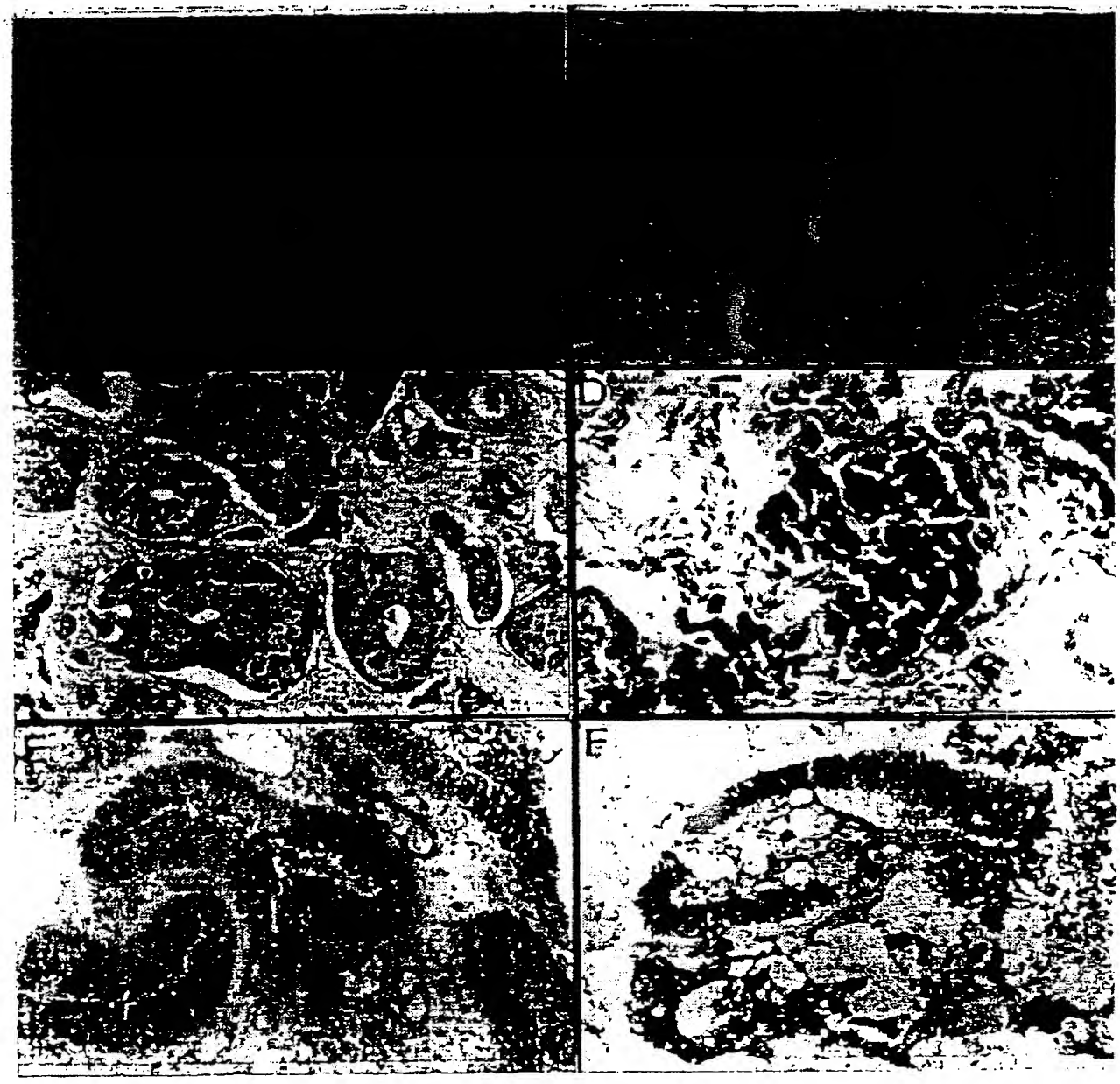
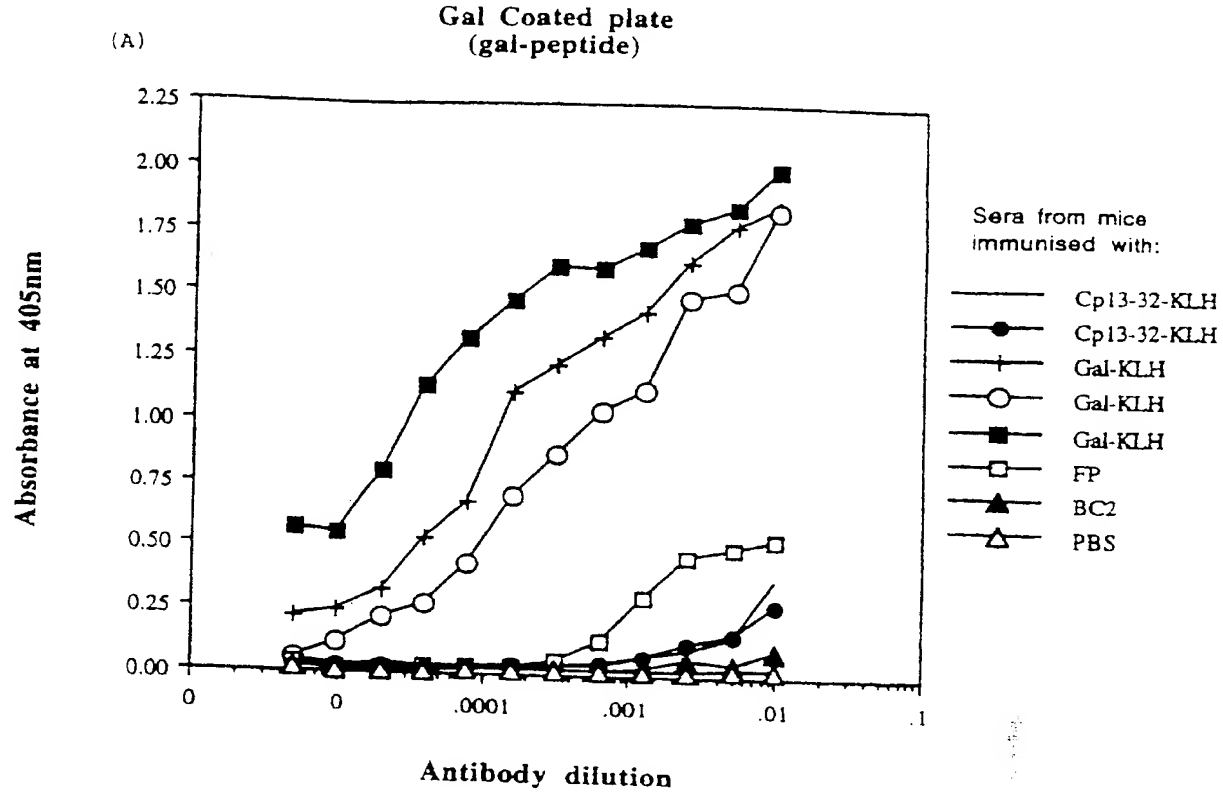


FIG.12

(A)



(B)

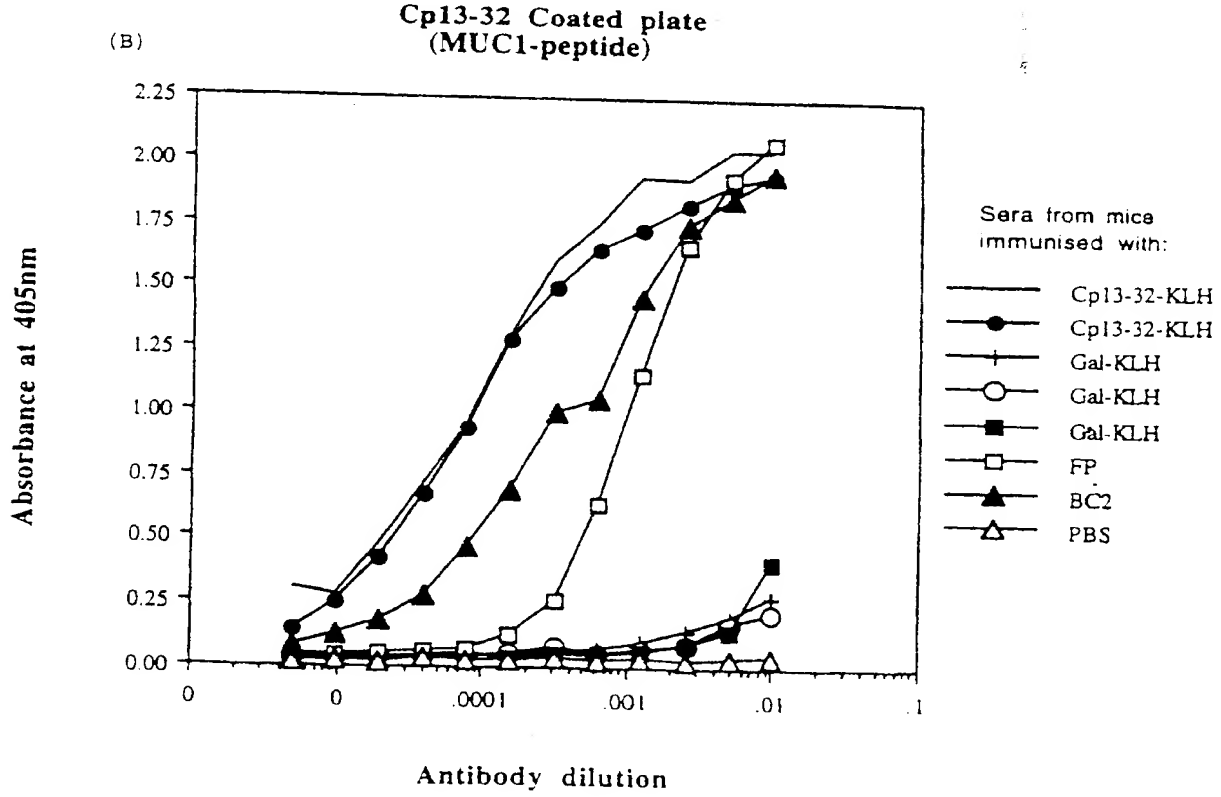


FIG. 13

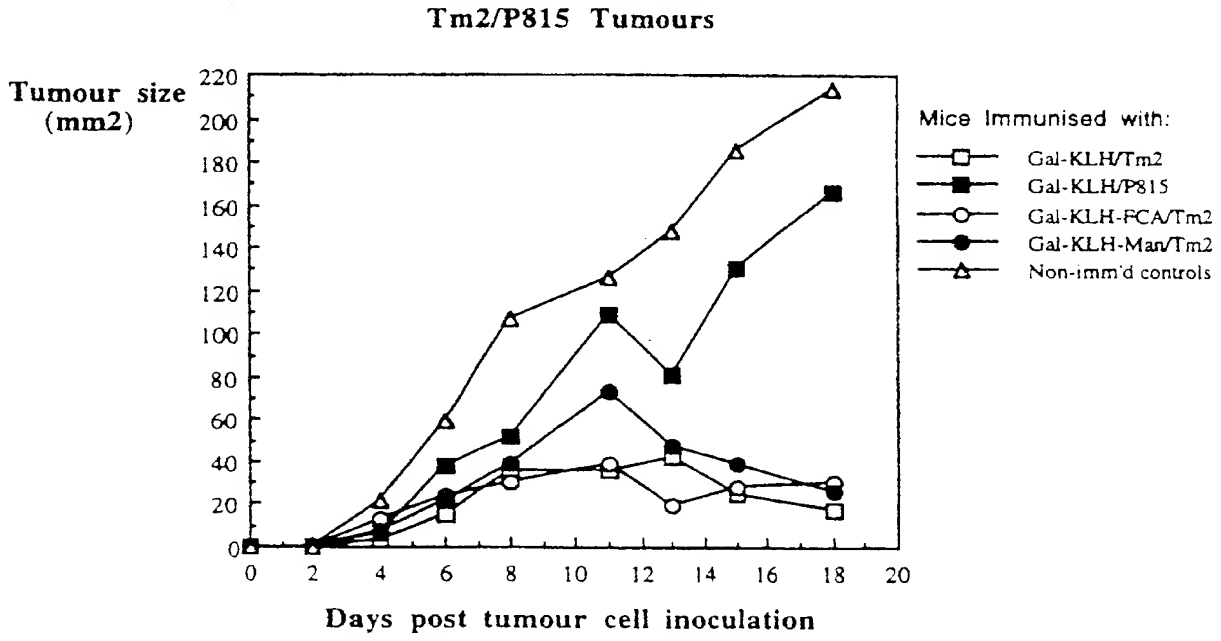


FIG. 14

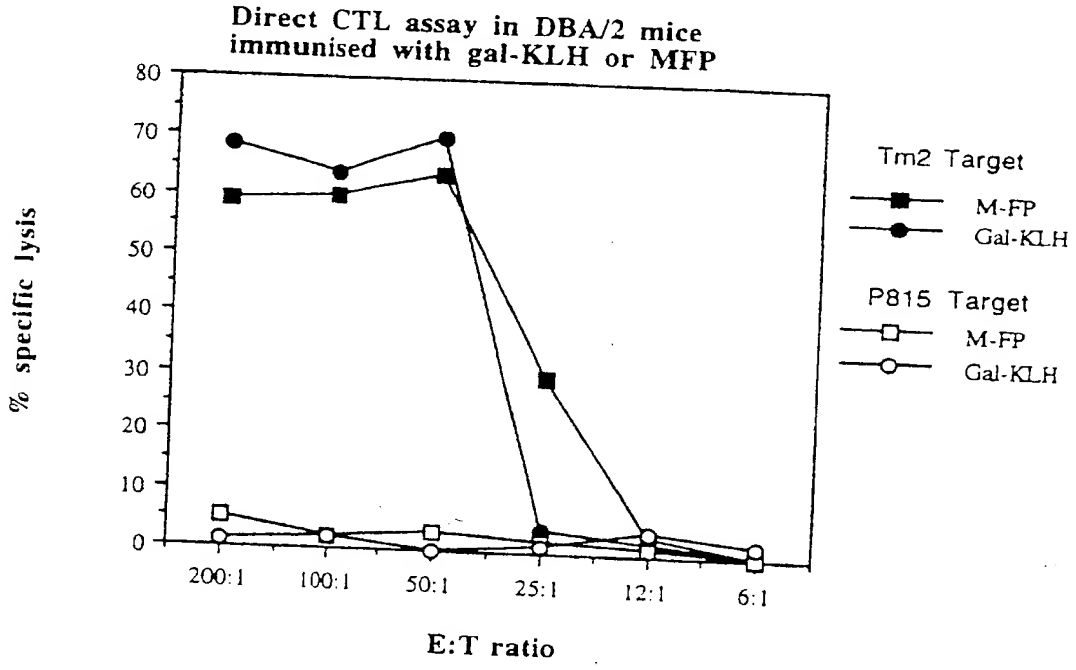

Direct CTL assay in DBA/2 mice
immunised with gal-KLH or MFP
% specific lysis
80
70
60
50
40
30
20
10
0
200:1
100:1
50:1
25:1
12:1
6:1
E:T ratio
Tm2 Target
M-FP
Gal-KLH
P815 Target
M-FP
Gal-KLH

FIG. 15

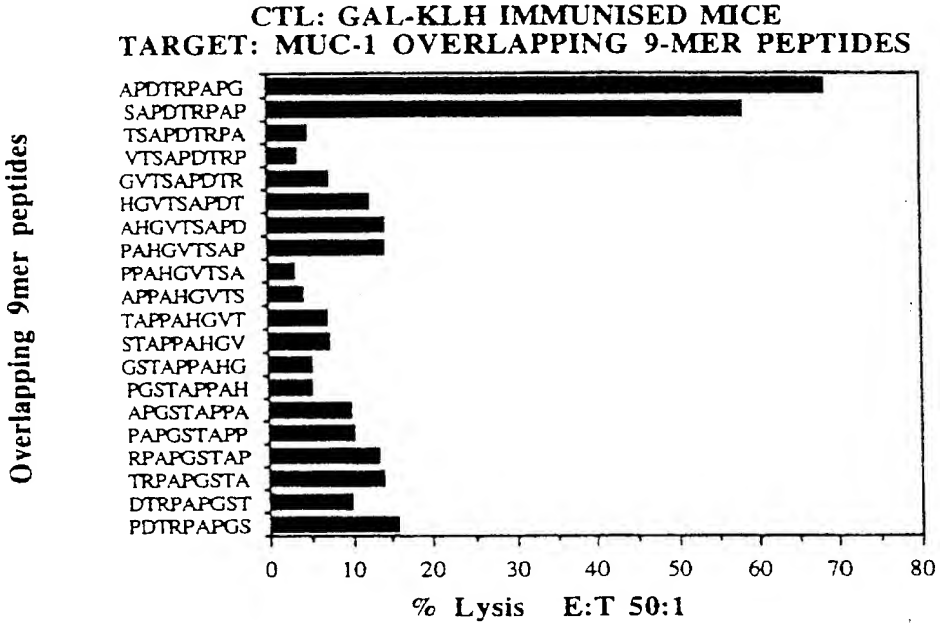

CTL: GAL-KLH IMMUNISED MICE
TARGET: MUC-1 OVERLAPPING 9-MER PEPTIDES
Overlapping 9mer peptides
APDTRPAPG
SAPDTRPAP
TSAPDTRPA
VTSAPDTRP
GVTSAPDTR
HGVTSAPDT
AHGVTSAPD
PAHGVTSAP
PPAHGVTSA
APPAHGVTS
TAPPAHGVT
STAPPAHGV
GSTAPPAHG
PGSTAPPAH
APGSTAPPA
PAPGSTAPP
RPAPGSTAP
TRPAPGSTA
DTRPAPGST
PDTRPAPGS
0
10
20
30
40
50
60
70
80
% Lysis E:T 50:1

FIG. 16

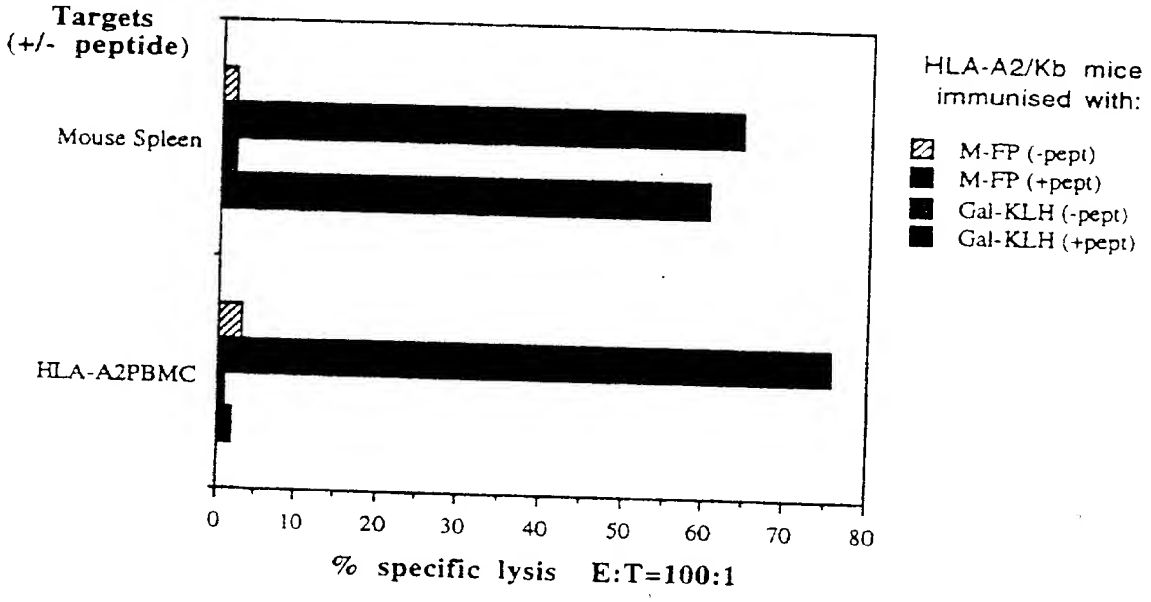
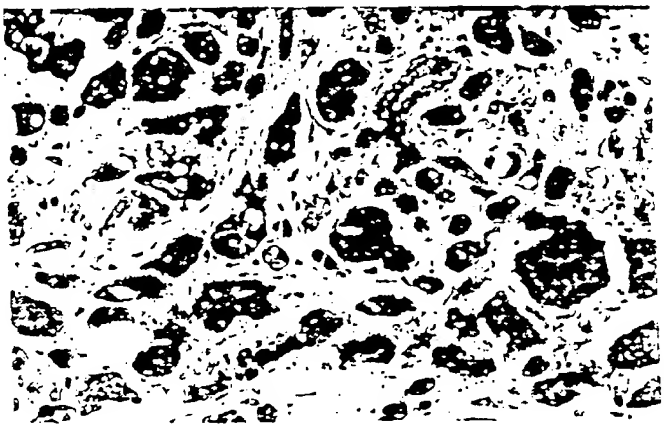
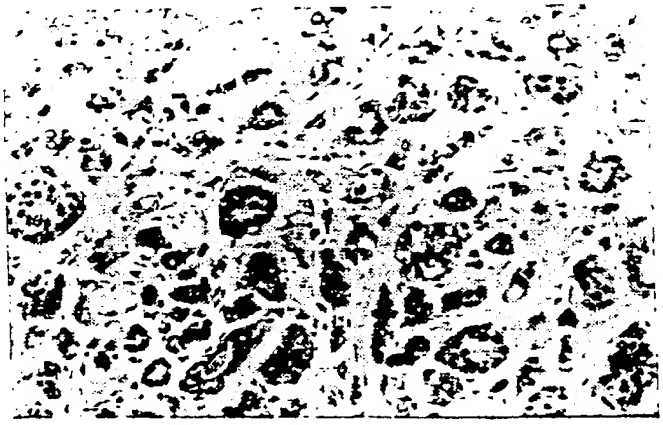


FIG. 17

A



B



INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 96/00617

A. CLASSIFICATION OF SUBJECT MATTER

Int Cl[6]: A61K 38/14, 38/04, 38/10, 38/16, 39/395

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : C07K, C12N, A61K, G01N. Chemical Abstracts. All Through Electronic Databases

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Sequence Search and Medline Through Electronic Databases

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
DERWENT database: WPAT & JAPIO Keywords: 1) (GAL(5N)GAL) OR (GALACTOSE(5N)GALACTOSE); 2) 1 (10N) (ANTIBOD: OR ANTI( )BOD:); 3) MUCIN# OR MUC#; 4) LECTIN#; (5) 3 and 4; (6) 2 or 5.
Chemical Abstracts Search: 1) GAL(5N)GAL; 2) GAL(5N)GAL/IT; 3) 1 or 2; 4) LECTIN#; 5) ANTIBOD?; 6) 3 and 5; 7) 6 and 4.
Medline Search: 1) GAL(5N)GAL; 2) GALACTOSE (5N) GALACTOSE; 3) ANTIBOD?; 4) 1 (20N) 3; 5) 3 (20N) 2; 6) 4 or 5).
Sequence Search through STN: 1) [WYF][SEADNIG]SEADNIG][WYF] as partial peptide sequences; 2) 1 and "sequence length < =200"; 3) 2 and (GAL(5N)GAL)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ARKLIE et al: "Differentiation Antigens Expressed by Epithelial Cells in the Lactating Breast Are Also Detectable in Breast Cancers", Int. J. Cancer, vol 28, pp. 23-29, 1981. See entire document	1

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 December 1996	11 DEC 1996
Name and mailing address of the ISA/AU AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA Facsimile No.: (06) 285 3929	Authorized officer ROBYN PORTER Telephone No.: (06) 283 2318

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INTERNATIONAL SEARCH REPORT

International Application No.
PCT/AU 96/00617

C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages *(Remove spaces when completed if the page is too long)*	Relevant to claim No.
	GENDLER and SPICER: "Epithelial Mucin Genes", Annu. Rev. Physiol., vol 57, pp. 607-634, 1995.	
X	See page 607, lines 13-15; page 609, first 4 lines of last paragraph; page 613, Section: "Functions of MUC1"; page 614, Section: "Rat Ascites ... ASGP-1 and ASGP-2", page 617 lines 16-20; pages 619-620; Section: "MUC5A"; pages 624-625, Section: "FIM-A.1".	1, 5
	WO 95/18145 (ILEXUS PTY LTD) 6 July 1995, IPC[6] C07K 9/00, 14/47, 14/705, 17/10, 19/00; A61K 39/00.	
X	See entire document, especially claims 1, 3, 6, 8, 11, 13 19, 20	1, 5, 6

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No.
PCT/AU 96/00617

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member (To put a line under the citations tab to the first point on the next row and press F8)					
WO	95/18145	AU	81728/94	AU	13081/95	CA	2135833
		EP	659768	JP	7206707		

END OF ANNEX

Form PCT/ISA/210 (extra sheet) (July 1992) ccphin